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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

BACKGROUND DOCUMENT/ ENVIRONMENTAL EXPLANATION FOR PROPOSED INTERSTATE RAIL CARRIER NOISE EMISSION REGULATIONS

MARCH 1974

OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON, D.C. 20460

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FOREWORD

The study of railroad noise is relatively new. Most of the information and data contained in this report has been generated during the past year. It is important to note that this report and the proposed regulations are an initial step in a continuing effort to understand and reduce railroad noise.

The Agency wishes to acknowledge the cooperation of a multitude of parties and to extend its appreciation for their efforts. Those parties include, but are by no means limited to, The Department of Transportation,and the Association of American Railroads, and the National Bureau of Standards.

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SECTION 1

PROLOGUE

STATUTORY BASIS FOR ACTION

Through the Noise Control Act of 1972 (86 Stat. 1234), Congress established a national policy "to promote an environment for all Americans free from noise that jeopardizes their health and welfare." In pursuit of that policy, Congress stated, in Section 2 of the Act, "that while primary responsibility for control of noise rests with State and local governments, Federal action is essential to deal with major noise sources in commerce, control of which requires national uniformity of treatment." As a part of this essential Federal action, Section 17 requires the Administrator to publish proposed noise emission regulations that "shall include noise emission standards setting such limits on noise emissions resulting from operation of the equipment and facilities of surface carriers engaged in interstate commerce by railroad which reflect the degree of noise reduction achievable through the application of the best available technology, taking into account the cost of compliance."

These two sections of the Act establish the criteria the Administrator has followed in the development of these proposed regulations. Section 17 does not contemplate the promulgation of regulations covering every aspect of the massive, complex interstate railroad industry, but only those on noise emissions from particular equipment and facilities of that industry. The types of equipment and facilities to be covered by Federal regulations are those that are "major noise sources in commerce," which require "national uniformity of treatment." The need for national uniformity of treatment depends largely upon interference with interstate commerce that would be caused by the lack of national uniformity. Regardless of whether or not there are Federal regulations on noise emissions from any type of interstate railroad equipment or facility under Section 17, the states and localities are barred by the Commerce Clause of the Constitution from imposing any regulations that would constitute an undue burden on interstate commerce.

Regulations under Section 17 are to be promulgated only after consultation with the Secretary of Transportation in order to ensure appropriate consideration for safety and technological availability. They are to take effect after such period as the Administrator finds necessary, after consultation with the Secretary of Transportation, to permit the development and application of the requisite technology, giving appropriate consideration to the cost of compliance within such period. Final regulations are to be promulgated within 90 days after publication of the proposed regulations and may be revised from time to time in accordance with Subsection 17(a)(2) of the Noise

Control Act. These regulations under Section 17 of the Noise Control Act shall be in addition to any regulations that may be proposed under Section 6 of the Act.

Section 17(b) of the Noise Control Act requires the Secretary of Transportation, after consultation with the Administrator, to promulgate regulations to ensure compliance with all standards promulgated by the Administrator under Section 17. The Secretary of Transportation shall carry out such regulations through the use of his powers and duties of enforcement and inspection authorized by the Safety Appliance Act, the Interstate Commerce Act, and the Department of Transportation Act. Regulations promulgated under Section 17 shall be subject to the provisions of Sections 10, 11, 12, and 16 of the Noise Control Act.

INTERNAL EPA PROCEDURE

The rulemaking process of EPA started with the publication of an Advanced Notice of Proposed Rulemaking in the *Federal Register*. At that time EPA informed the public of the requirement that regulations be developed and requested that pertinent information be submitted to the Agency for consideration. In the case of interstate rail carrier regulations, a task force was formed about the same time and was composed of Federal, State, and local government officials and consultants. The task force product was a recommendation to the Office of Noise Abatement and Control as to which regulatory action should be taken. The Office of Noise Abatement and Control considered that recommendation along with the recommendations of the EPA Working Group, which is comprised of representatives from various parts of the Agency. After the Deputy Assistant Administrator for Noise Control Programs approved the proposed regulations, they were submitted to the Assistant Administrator for Hazardous Materials Control who has responsibility for the Noise Control Program as well as four others. After the Assistant Administrator's approval, the proposed regulations were submitted to the EPA Steering Committee, which is comprised of all the Deputy Assistant Administrators of EPA. Upon the Steering Committee's approval, the proposed regulations were forwarded to the Office of Management and Budget, and other interested Federal agencies for review. After these comments were analyzed and satisfactorily addressed, the proposed regulations were published in the *Federal Register* for public comment. After public comments are analyzed a recommendation for the final regulations will be prepared and the above process will be initiated again, culminating in the promulgation of the regulations.

PREEMPTION

Under Subsection 17(c)(1) of the Noise Control Act, after the effective date of these regulations no State or political subdivision thereof may adopt or enforce any standard applicable to noise emissions resulting from the operation of locomotives or railroad cars of surface carriers engaged in interstate commerce by railroad unless such standard is identical to the standard prescribed by these regulations. Subsection 17(c)(2), however, provides that this section does not diminish or enhance the rights of any State or political subdivision thereof to establish and enforce standards or controls on levels of environmental noise, or to control, license, regulate, or restrict the use, operation, or movement of any train if the Administrator, after consultation with the Secretary of Transportation, determines that such standard, control, license, regulation, or restriction is necessitated by special local conditions and is not in conflict with regulations promulgated under Section 17.

Conversely, Subsection 17(c)(1) does not in any way preempt State or local standards applicable to noise emissions resulting from the operation of any equipment or facility of interstate railroads not covered by Federal regulations. Thus, under the proposed regulations, the States and localities will remain free to enact and enforce noise standards on railroad equipment and facilities other than trains without any special determination by the Administrator. Only after a Federal regulation on noise emissions resulting from the operation of a particular type of railroad equipment or facility has become effective must the States and localities obtain a special determination by the Administrator under Subsection 17(c)(2) in order to adopt or enforce their own differing noise standards on that equipment or facility.

Some types of railroad equipment and facilities on which no Federal noise standards or regulations have become effective, and which may, therefore, be subjected to State and local noise standards without any special determination by the Administrator, may include other types of equipment or facilities that are covered by preemptive Federal regulations. Railroad maintenance shops, for example, may from time to time emit the noise of locomotives undergoing tests along with noises common to many industrial operations such as forging and grinding. Also, railroad marshaling and humping yards include locomotives among their many types of noise sources.

In most instances, State or local standards on non-Federally regulated equipment or facilities of railroads can be met without affecting the Federally regulated equipment within them. Standards on noise emission from repair shops, for example, can be met by many measures including improved sound insulation in the walls of the shop, buffer zones of land between the shop and noise-impacted areas, and scheduling the operation of the shop to reduce noise at those times of the day when its impact is most severe. Standards on railroad marshaling and humping yards can be met by a variety of steps including: reducing the volume of loudspeaker systems by using a distributed sound system or replacing speakers with two-way radios, reducing noise emissions from equipment not covered by Federal regulations, installing noise barriers around retarders and noisy equipment, buying additional land to act as a noise buffer, and locating noisy equipment such as parked refrigerator cars or idling locomotives as far as possible from adjacent noise-sensitive property. Since State or local regulations on noise emissions from railroad facilities that the railroad can meet by initiating measures such as these are not standards applicable to noise emission resulting from the operation of locomotives or railroad cars, they would not be preempted by the proposed regulations. Thus no special determination by the Administrator under Subsection 17(c)(2) would be necessary. State or local noise standards on facilities involved in interstate commerce such as railroad marshaling yards are, of course, subject to Constitutional prohibition if they are so stringent as to place an undue burden on commerce.

In some cases, however, a State or local noise standard that is not stated as a standard applicable to a Federally regulated type of equipment or facility may, in effect, be such a standard if the only way the standard can be met is by modifying the equipment to meet the Federal standard applicable to it. This would be the case, for example, if after the proposed regulations become effective a State or locality attempted to adopt or enforce a limit on noise emissions from railroad rights-of-way in urban areas that could not reasonably be met by measures such as noise barriers. Such a standard, would, in effect, require modifications to trains even though they met the Federal standards, and would be preempted under Subsection 17(c)(1). It could not stand if it differed from the Federal standards, unless the Administrator made the determinations specified in Subsection 17(c)(2). The same would be true of any State or local standard on railroad yards that could not reasonably be met except by modifying locomotives or railroad cars to comply with the proposed Federal standards.

State or local use or operation regulations directly applicable to noise emissions resulting from the operation of Federally regulated equipment and facilities can, of course, stand if the Administrator makes the determinations specified in Subsection 17(c)(2) regarding them.

State or local noise emission standards directly applicable to noise emissions resulting from the operation of Federally regulated equipment and facilities may also stand without any special determination by the Administrator if those standards are identical to the Federal standards. By adopting such identical standards, States and their political subdivisions can add their enforcement capability to that of the Department of Transportation. The Environmental Protection Agency recommends and encourages such adoption of standards identical to the Federal standards.

SECTION 2

DATA BASE FOR THE REGULATION

The program for compiling data on train noise began with a search for already existing data. By compiling the existing data, it was possible to avoid repeating the few measurements completed by others, and the limitations of the existing data indicated what measurements needed to be made to extend the data. Technical journals were searched for reports of pertinent measurements. Published accounts of measurements in Europe and Asia were considered along with the accounts of measurements in the United States and Canada. A bibliography of relevant articles appears after Section 9.

Much of the needed data was obtained under contract by acoustical consultants. Some data were obtained through informal communication with members of the acoustics community to obtain unpublished accounts of measurements and proceedings of appropriate seminars. Leaders in the engineering departments of the two locomotive manufacturers that remain in business (Electro-Motive Division of General Motors–EMD, and General Electric–GE) were also interviewed in order to ascertain the extent of their data files, as well as to determine what problems may be created by attempts to control locomotive noise. At a meeting hosted by the Association of American Railroads, EMD and GE engineers reported measurements of locomotive noise and discussed some possible effects of locomotive noise controls. Three leading muffler manufacturers (Donaldson, Harco Engineering, and Universal Silencer) were contacted in order to evaluate the feasibility and the impact of fitting locomotives with exhaust mufflers.

Railroad company personnel who worked in various capacities at various levels were contacted in order to determine the mix of equipment used by railroads, the configurations of properties and equipment, scheduling of operations, and modes of operation. In particular, yard masters, yard superintendants, or engineering personnel were contacted to obtain information about yard configuration, layout, and equipment. Railroad personnel were asked for information related to schedules and speeds of trains. The railroad companies that participated are listed in the bibliography at the end of this report.

SECTION 3

THE RAILROAD INDUSTRY

ECONOMIC STATUS

There are currently 72 Class I railroads in the U.S.* These tend to break down into two groups: large transportation companies such as the Union Pacific or the Penn Central and railroads that are owned by large industrial firms such as U.S. Steel. The latter roads primarily provide transportation services to the "parent company." Since railroads are regulated by the Interstate Commerce Commission (ICC), the degree of competition is also regulated. The size of the firms has in many cases been determined by whether the ICC has allowed or disapproved mergers. Most large roads have grown through mergers. In addition, the financial power of some roads results from their nontransportation activities.

The total tonnage of freight moved in the U.S. has been rising over time, but the transportation sector of the economy has declined in relative importance. In 1950, 5.6% of national income originated in the transportation sector; by 1968 this figure declined to 3.8% and has remained at about that level. This trend reflects the higher relative growth rates in those industries that require a smaller transportation input.

The rail industry has been declining even more rapidly than the transportation sector. In 1950 the rail sector constituted 53% of the national income originating in the transportation sector. By 1968 it had declined to 25.8% of the transportation sector and has remained relatively stable since then. Table 3-1 summarizes these statistics.**

Accompanying the decline in the rail sector's share in national income originating in the transportation sector, the proportion of total freight hauled by rail has declined. In 1940 the railroads hauled 63.2% of all freight, dropping to 44.7% by 1960 and 39.9% by 1970. Motor carriers and oil pipelines have rapidly increased their share during this period. Air freight has increased more rapidly than either motor carriers or pipelines but it accounts for only .18% of total freight. In spite of the decreasing proportion of shipments by rail, the total volume of freight hauled by rail increased from 411.8 million ton miles in 1940 to 594.9 in 1960 and to 768.0 in 1970. Table 3-2 summarizes these trends.

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*Class I railroads are those having annual revenues of $5 million or more. They account for 99% of the national freight traffic.

**Unless otherwise stated, the data presented in Tables 3-1 through 3-6 were obtained from the Statistical Abstract of the United States (1971 and 1972).

TABLE 3-1
NATIONAL INCOME ORIGINATING IN THE TRANSPORTATION AND RAIL SECTORS
($ In Billions)

Year	National Income	Transportation	Transportation as % of National Income	Rail	Rail as % of Transportation
1950	$241.1	$13.4	5.6%	$7.1	53.0%
1960	414.5	18.2	4.5	6.7	36.8
1965	564.3	23.2	4.1	7.0	30.2
1968	712.7	27.1	3.8	7.0	25.8
1969	769.5	29.2	3.8	7.4	25.3
1970	795.9	29.5	3.7	7.2	24.4

TABLE 3-2
INTERCITY FREIGHT (In Millions of Ton Miles)

Year	Total Freight Volume in 10^6 Ton Miles	Rail Freight in 10^6 Ton Miles	Rail %	Motor Vehicles %	Oil Pipelines %	Air %	Inland Water %
1940	651.2	411.8	63.2	9.5	9.1	.002	18.1
1956	1376.3	677.0	49.2	18.1	16.7	.04	16.0
1960	1330.0	594.9	44.7	21.5	17.2	.06	16.6
1965	1651.0	721.1	43.7	21.8	18.6	.12	15.9
1968	1838.7	765.8	41.2	21.6	21.3	.16	15.9
1969	1898.0	780.0	41.1	21.3	21.7	.17	15.8
1970	1921.0	768	39.9	21.44	22.4	.18	15.98

Rail passenger service declined from 6.4% of intercity travel in 1950 to less than 1% in 1970. The real impact of railroads on the national economy is in terms of freight rather than passengers. The decline of the rail industry's share of the transportation sector is less dramatic when passenger service (air, local, suburban, and highway) is eliminated from calculations. Table 3-3 gives the transportation sectors' percentage contributions to national income, less the passenger sectors mentioned above, and the rail industry's percent of the transportation sector.

From comparison of Tables 3-1 and 3-3, it can be seen that the freight sector has declined more rapidly than the total transportation sector. It can also be seen that the railroads' decline is somewhat less dramatic in terms of freight alone than in terms of both freight and passenger service.

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TABLE 3-3

PERCENT OF NATIONAL INCOME ORIGINATING IN THE TRANSPORTATION SECTOR (LESS AIRLINE AND LOCAL SUBURBAN AND HIGHWAY PASSENGERS) AND THE RAIL SECTOR AS A PERCENT OF TRANSPORTATION

Year	Transportation* (Adjusted) as % of National Income	Railroads as % of Transportation (Adjusted)
1950	4.8%	61.7%
1960	3.7	44.1
1965	3.3	37.6
1968	3.0	33.0
1969	3.0	32.3
1970	2.9	Not Available

*Transportation minus air carriers and local suburban and highway passengers.

EMPLOYMENT

The railroads' importance as a source of employment within the economy has decreased along with their share of the nation's transportation output. In 1950 the railroads accounted for 2.7% of all employees in nonagricultural establishments. By 1970 this had fallen to less than 1%. Not only has the relative importance of railroads declined but also the absolute level of employment from 1950 to 1970 decreased by over 50%, as shown in Table 3-4.

Wages in the rail sector have consistently been above the average of all manufacturing employees and this differential has increased over the years. In 1950 the average hourly compensation in the rail sector was $1.60, which was 110% of the average hourly compensation in manufacturing. In 1968 average compensation was $3.54, or 118% of that in manufacturing. By 1971 rail compensation had increased to 126% of the average compensation in the manufacturing sector.

Increases in wage rates in the rail sector have been greater than the increases in the wage rates in the manufacturing sector. Using 1967 as the base (= 100), the index of wage rates in manufacturing in 1970 was 121.6 while the rail industry index was 125.6. Over the same period the increase in productivity in the rail industry has been less than productivity increases in manufacturing. In 1970 the index of output for all railroad employees was 109.9* while in manufacturing it was 111.6 (using a 1967 base of 100). Table 3-5 summarizes the wage and productivity data.

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*Computed on the basis of revenue per man hour.

TABLE 3-4
EMPLOYMENT IN THE RAIL INDUSTRY RELATIVE TO THE NATIONAL ECONOMY

Year	National Employees in All Nonagricultural Establishments (1000)	Railroad Employment (1000)	Railroad as % of National
1950	45,222	1220	2.7%
1960	54,234	780	1.4
1965	60,815	640	1.1
1968	67,915	591	.9
1969	70,274	578	.8
1970	70,664	566	.8

TABLE 3-5
INDEX OF OUTPUT PER MAN HOUR AND WAGES
(1967 = 100)

Year	Rail Wage	Manufacturing Wage	Rail Productivity	Manufacturing Productivity
1950	41.5	44.7	42.0	64.4
1960	74.3	76.6	63.6	79.9
1965	88.9	91.2	90.8	98.3
1968	106.3	107.1	104.4	104.7
1969	113.6	113.9	109.3	107.7
1970	125.6	121.6	109.9	116.6

The fact that productivity increases have not kept pace with wage rate increases indicates that unit labor cost is rising.

In the years since 1970, wages in the rail industry have, as in most industries, increased rapidly. The index of wages in 1971 was 136.8; in 1972, 136.8; and in 1973, 165.4 (estimated).

HEALTH OF THE INDUSTRY

There are a number of measures one might use to judge the "health" or financial stability of the rail industry. Two of these are the rate of return on stockholders' equity and the percent of revenue carried through to net operating revenue. Shareholders' equity is the excess of assets over liabilities, which is equal to the book value of capital stock and surplus.

In 1971 the rate of return on stockholders' equity for all manufacturing firms was 10.8%. The rates of returns in some selected industries are as follows:

instruments, photo goods, etc.	15.8%
glass products	11.1%
distilling	9.9%
nonferrous metals	5.2%

The return for the total transportation sector was 3.1%. Railroads showed a 2.1% on stockholders' equity, slightly above the airlines' 2.0%.

The rate of return on stockholders' equity increased from 1.3% in 1971 to 3.0% in 1972. The use of industry data, however, tends to give a misleading impression of the industry.*

The Eastern District had a negative rate of return for the three years from 1970 to 1972 while both the Southern and Western Districts had positive and increasing rates of returns. The Southern District showed an increase from 5.2% to 6.1% and the West from 3.7 to 5.1%. The rates of returns in these districts are well above the 3.1% for total transportation and are about equal to the textile and paper industries.

These trends indicate that the problem in the rail industry is not with all districts but primarily with roads in the Eastern District. Using operating ratios** as the measure of financial stability, one draws the same conclusions.

The historical trends in the profitability of the industry can be measured by the percent of gross revenue that is carried through to net operating income before Federal income taxes. This measure is similar to the rate of return on sales before taxes. For the industry as a whole, the percent of gross revenue carried through has been declining. This is also true of each district, with the Eastern being the worst. Table 3-6 summarizes these trends.

Although the rail industry performs poorly when compared with other industries, the performance of the Southern and Western Districts is much better than the Eastern. In fact, one would conclude that compared with nonregulated industries such as steel, the Southern and Western roads are reasonably good performers. Compared with other regulated industries, such as public utilities (10.5% return on stockholders' equity) and telephone and telegraph companies (9.5% return on stockholders' equity), the railroads' rate of return is low. One point that should be made is that railroads follow a "betterment" accounting procedure, which tends to overstate the value of their assets. We have not attempted to adjust rate of return in the rail industry to reflect this.

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*Because the railroads use a nonstandard accounting procedure (the so-called betterment technique), the rate of return is low relative to what it would be if they used a procedure comparable to those used in the nonregulated sector.

**Operating ratio equals operation expenses divided by operating revenues.

TABLE 3-6

PERCENT OF GROSS REVENUE CARRIED THROUGH TO NET OPERATING INCOME BEFORE FEDERAL INCOME TAXES

Year	All Class I RR's	Southern District	Eastern District	Western District
1950	17.3%	20.1%	12.0%	19.8%
1960	8.3	10.7	2.1	10.0
1965	11.0	12.1	10.0	11.6
1968	6.9	11.0	3.7	8.4
1969	6.6	12.1	2.7	8.0
1970	4.2	11.8	Nil	7.7
1971	4.0	10.3	0.5	7.2

The historical decline in the profitability of railroads came as a result of a decrease in the relative importance of high-weight, low-value cargo, which has traditionally been handled by rail. The increased competition from motor carriers and pipelines has further reduced the relative importance of railroads. Federal and State funding of highways has improved the competitive position of trucks and has led to the diversion of high-valued freight to motor carriers.

In 1935 when motor carriers came under Interstate Commerce Commission regulation, the value-of-service rate structure applied to railroads was also applied to motor carriers. (The value-of-service rate-making policy was originally applied to railroads in order to favor agricultural products. Under value-of-service rates, low-valued products have a lower rate per ton mile than do high-value products.*) This measure reduced intermodal price competition and in fact gave an advantage to trucks in carrying high-valued freight when they could give faster service. Railroads were unable to lower prices on this type of freight, which could have offset the faster service offered by trucks. A cost-based rate structure would probably allow railroads to recapture a larger share of the freight market.

The eastern roads, while subject to the same problems as the remainder of industry, have some additional ones. The decline of some manufacturing industries in the East has led to a more intense financial crisis among eastern roads. Also, their capital stock tends to be older and probably in poorer condition than that of the other roads. They spend a larger portion of total cost on yard switching than do either southern or western roads, probably because there are shorter hauls and a larger number of interchanges among roads. Since shippers pay for movement from one point to another (i.e., rate per mile), the competitive position of railroads tends to be diminished if these

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*These points are examined in an article by R.H. Harbeson in the 1969 *Journal of Law and Economics*, pp. 321–338.

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nonline-haul expenses rise. The greater yard-switching costs may also indicate that the quality of service in the East is lower than in other regions. Having rail cars sit in switching yards waiting for a train to be made up results in longer time in transit.

GROWTH

In projecting growth rates in any industry, one must assume to some extent that historical trends and relationships will continue to hold in the future. If these relationships do continue, then we might project rail freight based on projections of other factors. For example, we can project rail freight service on the basis of population or gross national product. If the population continues to consume similar commodities, if these commodities move by the same modes of transportation, and if increases in income are ignored, then projections based on accurate population projections will be valid.

The ton miles of railroad freight per capita in the U.S. has remained quite stable over the past five years. It was 3.73 in 1965, 3.77 in 1968, and 3.75 in 1970. Given this stability, short-run projections based on population growth may be quite accurate. Based on the population projections for the U.S., about a 1% annual increase over the next 5 years is estimated. This would mean an increase from 768 million ton miles in 1970 to about 822 million ton miles in 1975.

The rail industry's contribution to national income has remained relatively constant over the period from 1968 to 1970 at about 1%. The long-run rate of growth in GNP has been about 3.5%. Again, under the assumption that these historical relationships hold, the long-run growth should be around 3.5%.

One factor which may reverse these trends is that rail movement uses less energy than other forms of freight movement. A ton mile of freight moved by rail requires 750 British thermal units (BTU), while pipelines require 1850, trucks 2400, and air freight 63,000. The only mode of freight movement more efficient (in terms of energy) than rail is water, which requires 500 BTU.*

Energy may come to be an important factor, but it seems unlikely that rail freight will increase more rapidly than the growth in national income. The factor militating against a more rapid increase is that consumption patterns have continued to move toward more services and fewer manufactured products. This means a smaller transportation input. In addition, rising interest rates and greater product differentiation have caused shippers to be increasingly concerned with time in transit. The railroads' real advantage is in rates, not speed. However, the advent of transporting entire truck trailers by rail has aided in reducing delivery time substantially in areas where this is practiced.

**Business Week*, McGraw-Hill, Inc., September 8, 1973, p. 63.

SECTION 4

RAILROAD NOISE SOURCES

GENERAL

Noise is generated by railroad operations in two basic locations: in yards and on lines. In railroad yards, trains are broken down and assembled and maintenance is performed. Line operations involve the sustained motion of locomotives pulling a string of cars over tracks.

The hump yard is an efficient system for disengaging cars from incoming trains and assembling them into appropriate outgoing trains. A locomotive pushes a string of cars up a small hill, known as a hump, allowing each car to roll individually down the other side through a series of switches onto the appropriate track where a train is being assembled. As each car rolls down the hump, it is first slowed by the "master" retarder. The slowing, or retarding, is accomplished by metal beams that squeeze the wheel of the rail car. After the cars leave the master retarder, they coast into a switching area that contains many tracks. As each car is switched onto a particular track, it is slowed by a "group" retarder. After a car moves out of a group retarder, it is switched onto one of many (approximately 50) tracks in the "classification" area where the car collides with another car. The collision causes the cars to couple, forming a train. In some yards, the first car that moves into the classification area along a particular track is stopped by an "inert" retarder, so-called because the retaining beam is spring-loaded and requires no external operation. Inert retarders differ from the master and group retarders, which are controlled continuously by an operator or automatically by a computer.

All three of the retarding processes described above sometimes produce noise. When the beam of a master or group retarder rubs against the wheels, a loud squeal often is generated. The most significant noise generated by inert retarders occurs when a string of cars is pulled through the retarders. If the inert retarders are short and exert small forces, they may generate noise that is negligible compared with the noise generated by the group retarders. Some yards are equipped with inert retarders that can be manually or automatically released when a string of cars is pulled through them, thereby preventing retarder squeal. There are no inert retarders in some yards, so a man must ride some cars and brake them manually.

Noise is also produced when cars couple in the classification area of the yard. The impact points, and thus the origins of the noise, are scattered over the classification yard. The noise is impulsive, and sometimes it is followed by a thunderlike rumble that is audible for a couple of seconds after the impact.

Locomotive engines generate noise as the locomotives move cars around yards. When the locomotives are not in use, their engines are allowed to idle continuously (even overnight), which also results in significant noise. When the locomotives are in motion, their horns, whistles, and bells produce noise.

Some noise originates in the yard shops where locomotives and cars are repaired and maintained. Power tools and ventilation fans represent such sources. However, the most readily identifiable sources of shop noise are the locomotives themselves when undergoing testing.

Most yards are equipped with a number of loudspeakers that are used for conveying verbal instructions and warning sounds to workers in the yard. The speakers are scattered about the yard, and a given speaker issues sound on an unpredictable schedule.

Line, or wayside, noise—the noise in communities from passing trains—is comprised of many sources. The locomotive engine and its other components, such as cooling fans, generate high noise levels. The interaction of railroad car wheels with rails also results in significant noise. Wheel/rail noise is caused principally by impact at rail joints, giving rise to the familiar "clickety-clack," and by small-scale wheel and rail roughness. A severe form of wheel roughness that generates high noise levels is caused by flat spots developed during hard braking. Also, wheels squeal on very sharp curves and generate noise by flange-rubbing on moderate curves. The operation of such auxiliaries as refrigeration equipment also contributes to the overall noise level. Horns or whistles are blown at crossings and are louder than the other wayside noises. In addition, some crossings are equipped with stationary bells that sound before and during the passage of trains.

The remainder of Section 4 treats each of the noise sources mentioned above separately and in as much detail as the state of the art allows. Included in the discussion of each source is a description of abatement techniques.

CONSIDERATION OF RAILROAD NOISE SOURCES FOR FEDERAL REGULATION

Many railroad noise problems can best be controlled by measures that do not require national uniformity of treatment to facilitate interstate commerce at this time. The network of railroad operations is embedded into every corner of the country, including rights-of-way, spurs, stations, terminals, sidings, marshaling yards, maintenance shops, etc. Protection of the environment for such a complex and widespread industry is not simply a problem of modifying noisy equipment; it also gets into the minutiae of countless daily operations at thousands of locations across the country. The environmental impact of a given operation will vary depending on where it takes place, for example, whether it occurs in a desert or adjacent to a residential area. For this reason, state and local authorities are better suited than the Federal government to consider fine details such as the addition of sound insulation or noise barriers to particular facilities, the location of noisy equipment within those facilities as far as possible from noise-sensitive areas, etc. There is no indication at present that differences in requirements for such measures from place to place impose any burden on interstate commerce. At this time, therefore, it appears that national uniformity of treatment of such measures is not needed to facilitate interstate commerce, and would not be in the best interest of environmental protection.

However, since the national effort to control noise has only just begun, it is inevitable that some presently unknown problems will come to light as the effort progresses. Experience may teach that there are better approaches to some aspects of the problem than those that now appear most desirable. The situation may change so as to call for a different approach. Section 17 of the Noise Control Act clearly gives the Administrator of the Environmental Protection Agency authority to set noise emission standards on the operation of all types of equipment and facilities of interstate railroads. If in the future it appears that a different approach is called for, either in regulating more equipment and facilities, or fewer, or regulating them in a different way or with different standards consistent with the criteria set forth in Section 17, these regulations will be revised accordingly.

The Administrator has considered the following broad categories of railroad noise sources in order to identify those types of equipment and facilities that require national uniformity of treatment through Federal noise regulations to facilitate interstate commerce:

Office Buildings

Many, if not all, surface carriers engaged in interstate commerce by railroad own and operate office buildings. These buildings are technically "facilities" of the carriers. Like all office buildings they may emit noise from their air conditioning and mechanical equipment. But since each building is permanently located in only one jurisdiction and is potentially subject only to its regulations, it is not affected in any significant way by the fact that different jurisdictions may impose different standards on noise emissions from the air conditioning and mechanical equipment of other buildings. At this time, there appears to be no need for national uniformity of treatment of these facilities, and they are therefore not covered by these proposed regulations.

Repair and Maintenance Shops

Railroad repair and maintenance shops are similar in many ways to many nonrailroad industrial facilities, such as machine shops, foundries, and forges. All such facilities can reduce their noise impact on the surrounding community by a vareity of measures including reduction of noise emissions at the source, providing better sound insulation for their buildings, erecting noise barriers, buying more land to act as a noise buffer, scheduling noisy operations at times when their impact will be least severe, or simply moving noisy equipment to locations more remote from adjoining property. Such detailed and highly localized environmental considerations are best handled by local authorities. Like office buildings, shops are permanently located in only one jurisdiction and thus are not potentially subject to differing or conflicting noise regulations of other jurisdictions. At this time, therefore, there appears to be no need for national uniformity of treatment of these facilities, and they are not covered by these proposed regulations.

At times, railroad maintenance shops may contain major noise sources that do require national uniformity of treatment, such as locomotives. But the fact that some such individual noise sources within a shop may be subject to Federal noise emission regulations is irrelevant to the validity of State or local noise emission regulations applied to the shop as a whole, as long as the State or local regulation on the shop can reasonably be complied with without physically affecting the Federally regulated noise source within the shop (for example, by installing sound insulation in the shop building). This will be discussed further in the section on preemption below.

Terminals, Marshaling Yards, and Humping Yards

Like office buildings and shops, railroad terminals and yards are permanent installations normally subject to the environmental noise regulations of only one jurisdiction. Noise emissions from terminals and yards can also be reduced by many measures that do not require national uniformity of treatment and that can best be handled by local environmental authorities. These include measures such as building noise barriers around noise sources (for example, retarders), buying land to act as a noise buffer, locating noisy equipment as far as possible from adjacent noise-sensitive property, and reducing the volume of loudspeaker systems or replacing them with two-way radios. At this time, there appears to be no need for national uniformity of treatment of these facilities, and they are not covered by the proposed regulations.

Like railroad maintenance shops, marshaling and humping yards contain some noise sources that are covered by the proposed regulations. As is discussed in greater detail in the preamble to the proposed regulations, a State or local noise regulation on a railroad terminal or yard is in effect a regulation on the Federally regulated noise sources within the terminal or yard when it can be met only by physically altering the Federally regulated noise sources.

Track and Right-of-Way Design

Some steps can be taken to reduce noise emissions from railroad rights-of-way that do not in any way affect the operation of trains on the rights-of-way, such as speed limitations and the erection of noise barriers. State and local governments are much better situated than the Federal Government to determine if some noise-sensitive areas need such protection; and the existence of differing requirements for such measures in different areas does not at this time appear to impose any significant burden on interstate commerce. There is at present no need for national uniformity of treatment of such noise abatement techniques, and this source is therefore not covered by these regulations.

Horns, Whistles, Bells, and Other Warning Devices

This type of noise is different in nature from most railroad noise since it is intentionally created to convey information to the hearer. Railroad horns, whistles, bells, etc. are regulated at the Federal and State levels as safety devices rather than as noise sources. Federal safety regulations are confined to the inspection of such devices on locomotives, so as to ensure that, if present, they are suitably located and in good working order (Safety Appliance Act, 45 USCA; 49 Code of Federal Regulation, 121, 234, 236, 428, 429). State regulations are oriented toward specifying the conditions of use of these devices and, for the most part, do not specify any maximum or minimum allowable noise level for them. A recent survey of the 48 contiguous States (reference APP G) has revealed the following:

1. At least 43 States require that trains must sound warning signals when approaching public crossings.
2. 35 of these States specify some minimum distance from a public crossing at which a train approaching that crossing may sound a warning signal.
3. 3 States specify a maximum distance from a public crossing at which a train approaching that crossing may sound a warning signal.
4. 35 States specify that these warning signals must be sounded until the train reaches the crossing.
5. 3 States specify that these warning signals must be sounded until the train completely clears the crossing.
6. 16 States provide for exceptions to their regulations for trains operating in incorporated areas.
7. At least two States provide for exceptions to their regulations for trains approaching public crossings that are equipped with satisfactory warning devices.

Two frequently proposed solutions to eliminate the need for trains to sound warning devices when approaching public crossings are:

1. Eliminate all public grade level railroad crossings.
2. Install active protection systems (e.g., flasher-gate combinations) at all public grade level railroad crossings.

This first solution would be the most effective since it would eliminate the source of the problem, the public grade level railroad crossing. However, it would be extremely costly because it would involve the elevating or depressing of either the railroad line or the public thoroughfare at each public crossing. This solution may be infeasible for solving existing conditions but it should be seriously considered in all future public thoroughfare or railroad line construction projects.

The second solution, although it does not attack the source of the problem, does seem to be an effective protection measure in that it could eliminate the need for the sounding of warning signals by trains approaching public crossings. This solution has its drawbacks, however. Flasher-gate-type devices cost $30,000-$40,000 with some installations costing up to $60,000. In the State of Illinois there are 16,250 grade level crossings of which 1,625 have flasher-gate protection devices. To outfit the remaining 15,000 crossings with these devices in that state alone would cost $450 million or more. The nationwide cost of this solution would be prohibitive.

Since train horns, whistles, bells, etc., are designed to emit a great deal of noise in the interests of safety, and since any regulation restricting the noise output of these devices could be construed as contrary to these interests, no regulatory action affecting these devices is being proposed at this time.

From the information presented above, there seems to be a definite need to develop cheaper and more effective warning devices at public railroad crossings so that the use of train horns, whistles, bells, etc., can be minimized.

Trains

Unlike the categories of railroad equipment and facilities discussed above, train noise is potentially subject to the noise regulations of more than one jurisdiction. Trains are constantly moving from one jurisdiction to another, and it is not feasible to have them stopped at every political boundary and adapted to meet a different noise standard. Moreover, they constitute a major source of noise to people close to railroad rights-of-way. The various sources of train noise (other than warning devices) are therefore covered by these proposed regulations in order to facilitate interstate commerce through national uniformity of treatment of their control.

CHARACTER OF RAILROAD NOISE SOURCES AND ABATEMENT TECHNOLOGY

Locomotive Noise

The major noise-producing mechanism in diesel locomotive operations are engine exhaust, engine casing, cooling fans, and wheel/rail interaction. The levels of sound power generated by these mechanisms depend on a number of variables, particularly engine type, mechanical power, and throttle setting.

Three types of engines are currently in use: 2-stroke Rootes blown, 2-stroke turbocharged, and 4-stroke turbocharged. A turbocharged engine produces about 50% more power than does a Rootes blown engine. The number of cylinders on a diesel engine may be 8, 12, 16, or 20, with each cylinder having a displacement of 650 cu in. Each cylinder produces 125 hp when Rootes blown and 187.5 to 225 hp when turbocharged. These engines are employed on the two basic types of locomotive: the switcher, which is used primarily to shunt cars around the railroad yard and is powered by engines of under 1500 hp, and the road locomotive, which is used primarily for long hauls and is powered by engines of 1500 hp or more.

A diesel locomotive engine drives an electric alternator that produces electricity to run the electric traction motors attached to each axle of the locomotive. The rated power of the engine is the maximum electrical power delivered continuously by the alternator. The engine has eight possible throttle settings. As can be seen in Table 4-1, engine power and noise levels increase with throttle position. The data in this table are taken from a presentation given at the American Association of Railroads (AAR) meeting in August 1973 by the Electro-Motive Division (EMD) of General Motors Corporation and were developed from a study of load cycle information for a number of U.S. railroads. Of the approximately 27,000 locomotives in service on major railroads, about 20,000 were built by EMD. The percent of horsepower and percent of time given for each throttle position are typical of all locomotives. The dB(A) levels vary, of course, from engine to engine. The example here is for a 2000 hp EMD GP40-2 locomotive.

TABLE 4-1

EFFECT OF THROTTLE POSITION ON
ENGINE POWER AND NOISE LEVELS

Throttle Position*	% of Rated hp for Diesel Engines	% of Time at Throttle Position		dB(A) at 100 Ft for 2000 hp Engine
		Road Loco	Switcher	
Idle	0.75†	41	77	69.5
1	5	3	7	72.0
2	12	3	8	74.0
3	23	3	4	77.0
4	35	3	2	80.0
5	51	3	1	84.5
6	66	3	–	86.0
7	86	3	-	87.5
8	100	30	1	89.0*

*Three cooling fans were operating during measurement for throttle position 8, only one fan for other measurements.

†Locomotive auxiliary hp only—no traction.

As in Table 4-2, all measurements discussed in this section are A-weighted levels obtained by means of a microphone placed alongside a locomotive and referred to 100 ft, unless otherwise noted. Details of the measurement procedures are given in Appendices A and B.

During the course of this study, sound level measurements were made on individual locomotives at different power settings during load cell or dynamic brake testing. The results of these tests are shown in Table 4-2.

From the sample of locomotives measured at idle the range of sound level emission was 16.5 dB(A) with the maximum sound level sampled being 79 dB(A). Similarly, at the full power condition the range of sound level emissions was 7.5 dB(A) with a maximum level of 93 dB(A).

For purposes of separating the contributions of various components to overall engine noise levels, we have used the prediction schemes employed in the Department of Transportation Report of 1970.

The predictions involve (1) determining the mechanical power and type of engine required to perform a given task, (2) determining the throttle setting required to perform a given task, and

TABLE 4-2
LOCOMOTIVE NOISE LEVELS

Locomotive Make and Type	Horse-power	A-Weighted Sound Pressure Level at 100 Ft			Reference No. (See End of Section)
		Idle	Full Power Load Cell	Full Power Dynamic Brakes	
EMD-F7A	1500	66	86	–	1 (50 ft-6dB)
EMD-SW1500	1500	69	92	–	1 (50 ft-6dB)
EMD-GP40-2	3000	70	88	–	1 (50 ft-6dB)
EMD-GP40	3000	–	91*	–	1 (50 ft-6dB)
EMD-SD45	3600	–	86.5*	–	1 (50 ft-6dB)
EMD-SD45	3600	–	89*	–	1 (50 ft-6dB)
EMD-SD45	3600	–	90*	–	1 (50 ft-6dB)
EMD-SD45	3600	–	93*	–	1 (50 ft-6dB)
EMD-GP35	2500	79	92	–	2 (200 ft+6dB)
EMD-SW1500	1500	–	93	–	3
EMD-SW1500	1500	–	84.5	–	3 (w/pre '60 muffler)
EMD-GP/SD-38	2000	–	91.5	–	3
EMD-GP/SD-40	3000	72	89.5	–	3
EMD-SD-45	3600	–	90.5	–	3
GE-U30	3000	–	86	–	4 (50 ft-6dB)
GE-U25	2500	–	86	–	5 (50 ft-6dB)
Switcher	–	62.5	–	–	5
Switcher	–	63.5	–	–	5
Switcher	–	64;5	–	–	5
Switcher	–	66.5	–	–	5
Road	–	65.5	–	–	5
Road	–	66.5	–	–	5
Road	–	67.5	–	–	5
Road	–	71.5	–	–	5
Road	–	71.5	–	–	5
Road	–	72.5	–	–	5
EMD-GP-7	1500	64	88	–	6
EMDSD-35	2500	69	86	–	7
GE-U36B	3600	68	–	91	7
GE-U36B	3600	67	–	93	7
EMD-GP38	2000	66.5	88.5	–	7
EMD-GP-38	2000	67	–	88.5	7
GE-U36B	3600	66	–	90.5	7
GE-U36B	3600	66	–	85.5	7
GE-U36B	3600	64.5	–	90	7
GE-U36B	3600	65	–	89.5	7
EMD-GP40	3000	64.5	88	–	7
EMD-GP40	3000	69.5	88.5	–	7
EMD-GP40	3000	67	85.5	–	7
EMD-GP40	3000	68.5	88	–	7
EMD-GP40	3000	67	88	–	7
	Range	16.5	7.5	7.5	
	Mean	67.5	88.7	89.7	
Standard Deviation		3.305	2.484	2.325	

*Measured at Wayside

(3) converting from engine type and throttle setting to sound level. The expression for unmuffled diesel exhaust noise is

$$\text{dB(A) at 100 ft} = 92 + 10 \log (\text{hp}/1500) - 3\,(8\text{-throttle settings}) - T$$

where T is 6 for turbocharged engines and 0 otherwise. As can be seen in Figure 4-1, the predicted exhaust noise level for an EMD F7A locomotive at each throttle setting is very close to the measured total noise level. This result agrees well with the assumption that engine exhaust is the dominant source mechanism in locomotive noise. A similar expression is used in Ref. 4 to predict the contribution of casing-radiated noise.

Table 4-3 gives the exhaust and casing noise levels predicted by the techniques in Ref. 4 for a number of locomotives as well as total noise measurements made by BBN, EMD, and GE. The measured data were gathered while the locomotive was stationary and under full load (throttle position 8) on a test cell. The engine was loaded by feeding the electric current into a resistor bank.

As can be seen in this table, the contribution of casing noise to overall level appears to increase with mechanical power. Thus, for small locomotives where the level of casing noise is considerably lower than exhaust levels, an exhaust muffler could provide substantial reduction in total locomotive noise. For larger locomotives, exhaust muffling alone cannot reduce overall levels as much.

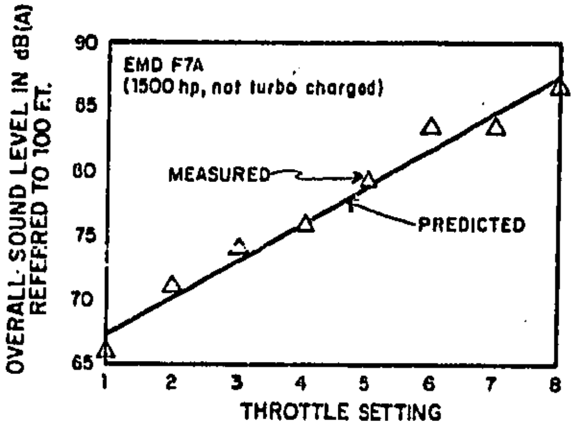

Figure 4-1. Measured Total and Predicted Exhaust Noise Levels

TABLE 4-3
COMPARISON OF PREDICTED AND MEASURED NOISE LEVELS AT 100 FT FOR VARIOUS EMD AND GE LOCOMOTIVES IN THROTTLE POSITION 8

Mechanical Power and Type	Predicted Exhaust db(A)	Predicted Casing db(A)	Measured db(A)	No. of Samples	Spread db(A)	Source
EMD 1000 hp Switcher	90	78	--	0	–	–
EMD 1500 hp Switcher	92	80	93	2	±1	BBN
EMD 2000 hp Road Locomotive	93	81	89	2	±2	BBN
EMD 3000 hp Road Locomotive	89	83	89.5	1	–	EMD
GE 300 hp Road Locomotive	89	85.5	86	1	--	GE
EMD 3600 hp Road Locomotive	90	84	89	4	±3	BBN
GE 3600 hp Road Locomotive	90	86.5	–	0	–	--

The average overall noise level for the EMD locomotives at 100 ft is 90 dB(A) ±4 db(A), where the variance includes allowances for all possible measurement and locomotive differences, for example, different observers and different test sites. The GE measurement for its 3000 hp locomotive is 86 dB(A) ±3 dB(A), again allowing for all possible measurement variations, slightly lower than those measured by EMD. The reason for this difference may be that on GE locomotives, the exhaust stacks rise about 6 in. above the hood, while on EMD locomotives the stacks are flush with the hood and radiate sound more efficiently.

In addition to exhaust and casing noise, the noise from cooling fans may be significant. Figure 4-2 shows that the noise from an EMD GP-40-2 3000 hp locomotive measured 9 dB(A) higher with three cooling fans running than with no fans running. Since it was necessary to open the engine access doors during the measurements, the recorded levels are somewhat higher than would be generated under normal operating conditions. However, there is little doubt that cooling-fan operation can contribute significantly to overall levels. The fans on GE engines run continuously, thus contributing to total noise level under all operating conditions. Fans on EMD locomotives are thermostatically controlled and run infrequently.

In summary, the major components of locomotive noise are, in order of significance, engine exhaust noise, casing-radiated noise, cooling fan noise, and wheel/rail noise. Table 4-4 shows average levels in dB(A) at 100 ft for each of these sources. Other sources, such as engine air intake,

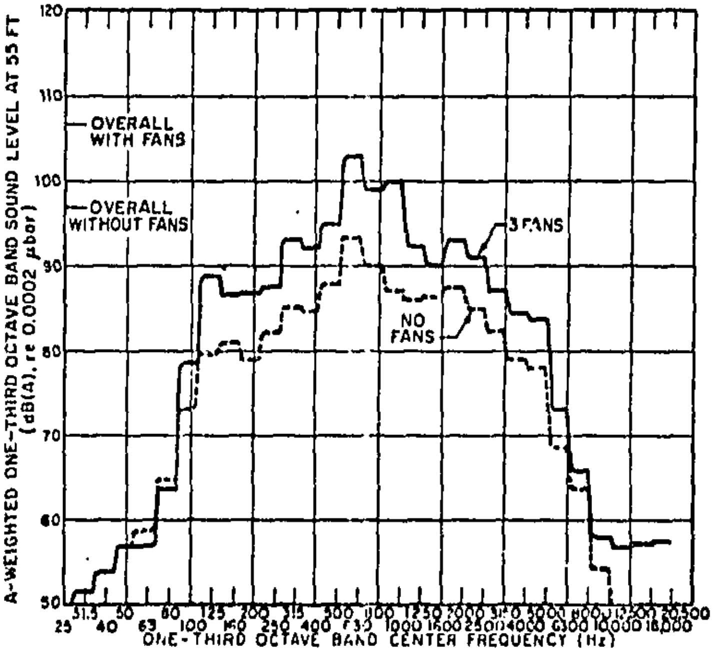

Figure 4-2. Effect of Fan Noise on the A-Weighted Spectrum of EMD GP40-2 Locomotive Noise at 55 ft (Engine Access Doors Open)

TABLE 4-4

SOURCE CONTRIBUTIONS TO LOCOMOTIVE NOISE LEVELS

(Based on Prediction Techniques of Ref. 4)

Source		dB(A) at 100 Ft (Throttle 8)
Exhaust		86–93
Casing		80–85.5
Cooling Fans		80–84
Wheel/Rail at 40 mph	Locomotive only	78
	Total train	81

traction motor blowers, and the traction motors themselves, have noise levels too far below the other source to be identified. Also, Rootes blown engines have a very unpleasant "bark" which does not show up in any generally used method of measurement.

Locomotive Noise Abatement via Equipment Modification

Mufflers

Since locomotives contribute most of the noise of railroad operations and since exhaust noise dominated locomotive noise, the first step in reducing locomotive sound levels is to require that each locomotive be fitted with an effective muffler. This section contains muffler manufacturers' estimates of various factors affecting the feasibility of supplying both new and in-service locomotives with mufflers.

One such factor is the amount of back pressure a muffler creates. Back pressures on the engine may affect its performance and life to a small extent. The engine must pump against the back pressure, thereby reducing the power that can be distributed to propel the train. Normally, this degradation in performance is about 1% when back pressures are held within manufacturers' limits. Back pressure may shorten engine life because when gases with increased temperature and density exhaust into a region of high pressure, they raise the temperature of exhaust valves and turbochargers. The following information on back pressure and its effects was determined by muffler manufacturers.

Engine Type	Back Pressure	Effect
Rootes Blown	47.5 in. H_2O measured at engine exhaust port	
Turbocharged	5 in. H_2O measured at exhaust stack	10°C rise in turbocharger temperature 20-hp loss on 3000 hp engine < 0.6% increase in fuel consumption

Mufflers have no appreciable effect on exhaust emissions; muffler-equipped locomotives give off insignificant incremental amounts of NO_x, CO, and smoke [EMD (1973)]. One potential problem manufacturers want to investigate further is that condensed, unburned hydrocarbons might give rise to a stack fire. This has never occurred on locomotives having mufflers, although it has happened on stationary installations.

Three manufacturers with some experience in fabricating mufflers for locomotives have been contacted and are prepared to help the railroads comply with the proposed regulations: Donaldson of Minneapolis, Minn.; Harco Engineering of Portland, Ore.; and Universal Silencer of Libertyville, Ill. The following are these manufacturers' estimates of the attenuation that could be achieved with their mufflers, the approximate cost of the mufflers alone, without any allowance for installation, and the amount of back pressure they create.

Donaldson has had some experience with the Chicago and Northwestern Railroad in equipping a locomotive with an off-highway truck type of muffler. The results were:

Muffler Cost – approximately $800 for two mufflers
Back Pressure – further testing necessary

Harco Engineering has achieved the following results for a switcher locomotive. The muffler is fitted to a Harco spark arrester.*

Attenuation – approximately 5 dB(A)**
Muffler Cost – $75

The results for road locomotives are:

Rootes Blown:

Attenuation – approximately 10 dB(A)**
Muffler Cost – $750

Turbocharged:

Attenuation – approximately 10 dB(A)**
Muffler Cost – $1000
Back Pressure – 13-20 in. H_2O(EMD claims that the back pressure is too high)

Universal Silencer has built mufflers for EMD locomotives (3 DRG and 40 Amtrack). According to EMD (presentation at AAR meeting, 1973) these mufflers achieved:

Attenuation – 9-10 dB(A) at full power
Muffler Cost – approximately $1200
Back Pressure – 3 in. H_2O

The estimated overall noise that would result from equipping various locomotives with mufflers that give 5 dB(A) and 10 dB(A) attenuation in throttle 8 is indicated in Table 4-5.

Muffler manufacturers have said that they could supply fully developed and tested muffler systems for all locomotives by the following dates.

HARCO	
Switchers	1 January 1974
Road	1 January 1976
DONALDSON	
All types	1 January 1976
UNIVERSAL SILENCER	
Turbocharged Locos	1 January 1976
Rootes Blown	1 January 1977
Switchers	1 January 1978

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*From EPA Docket 7201001, No. R007.

**This measurement was performed by the manufacturer.

TABLE 4-5

LOCOMOTIVE NOISE LEVELS EXPECTED FROM EXHAUST MUFFLING, THROTTLE 8

Locomotive Type	5 dB(A) Exhaust Muffling		10 dB(A) Exhaust Muffling	
	Total Noise Level [dB(A)]	Total Attenuation [dB(A)]	Total Noise Level [dB(A)]	Total Attenuation [dB(A)]
EMD 1000-hp Rootes Blown Switcher	86.0	4.0	82.0	8.0
EMD 1500-hp Rootes Blown Switcher	88.0	4.0	84.0	8.0
EMD 2000-hp Rootes Blown Road Locomotive	89.0	4.0	85.0	8.0
EMD 3000-hp Turbocharged Road Locomotive	86.5	3.5	84.5	5.5
GE (or Alco) 3000-hp Turbocharged Road Locomotive	87.5	3.0	86.5	4.0
EMD 3600-hp Turbocharged Road Locomotive	87.5	3.5	85.5	5.5
GE (or Alco) 3600-hp Turbocharged Road Locomotive	88.5	3.0	87.5	4.0

EMD and GE have said that they could fit mufflers on new locomotives by the following dates.

EMD

Turbocharged	Road	1 January 1976
Rootes Blown		1 January 1977
Switchers		1 January 1978*

GE

Turbocharged	1 January 1976

EMD and GE agree that mufflers can be incorporated in new locomotives. The cost of installing mufflers on locomotives must be compared with a total cost of $300,000 to $400,000 per locomotive (GE and EMD presentations to AAR meeting, 1973). The following methods would be used by each locomotive manufacturer in fitting mufflers on *new* engines.

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*Because of problems integrating with spark arrester.

New GE Road Locomotives

Mufflers would be installed above the engine and the hood roof would be raised 8 in. A locomotive would still clear the required 15-ft, 7-in. gauge. Cost = $1500 per locomotive.

New EMD Road Locomotives

Turbocharged: The muffler would be installed over the turbocharger. Mountings would have to be changed as would the roof structure, brake cabling, and extended range dynamic brakes. Cost = $2500 per locomotive.

Rootes blown: The muffler would be integrated with the spark arrester. There would be changes to the dynamic brake contactors, roof structure, and coolant piping. Cost = $3000 per locomotive.

New EMD Switchers

The muffler would be integrated with the spark arrester, but EMD is not quite sure how. Cost = $200–$500 (estimate based on Harco figures).

Retrofitting Older Locomotives

Retrofitting mufflers on locomotives involves finding out how many of each type of locomotive are still in service and adopting muffler installation procedure to the peculiarities of each model.

Table 4-6 illustrates the distribution of switchers in service, categorized by manufacturer.

TABLE 4-6
SWITCHER LOCOMOTIVES IN SERVICE

Manufacturer	Year Built	No. in Service
EMD	1940-59	3200
	1960-present	1100
ALCO	1940-61	950
GE	1940-58	116
Baldwin, Lima Hamilton	1946-56	415
Fairbanks Morse	1944-58	220
		TOTAL 6000

Very few new switchers are being built, only about 120 per year, since switchers appear to run indefinitely. Furthermore, old road locomotives can be downgraded for switching use.

Most switching locomotives built before 1960 were equipped with mufflers, but after 1960 railroads generally fitted spark arresters instead.

In general, there does not seem to be any difficulty in fitting a muffler to the exhaust stack above the hood of a switcher. This has already been done in many cases with spark arresters, resulting in some loss in visibility for the driver. Harco has designed and tested a muffler that integrates with its spark arrester. The Harco muffler costs $75. However, this unit may have inadequate muffling for the regulation or too high a back pressure. Keeping this in mind, we estimate the cost for other spark arresters to be $200 to $500 plus 1 man-day labor for installation.

The 8758 EMD Rootes blown road locomotives built before 1 January 1972 have less space for mufflers than the new model GP/SD 38-2. Care must be given to the siting of mufflers, but installation is considered to be possible. The dynamic brake grids will have to be resited, and the roof structure will have to be modified. Railroads might have changed exhaust systems on rebuilding. Discussions with a representative from Penn Central have led to the following cost estimates for fitting each of these older models with a muffler.

Muffler = $1500
Labor = 25 man-days ($/man-day = $46.40) (see Section 7)
Parts = $200–$500

Labor covers the resiting of dynamic-brake grids, plumbing and cabling, modifying the roof structure, and installing the muffler.

Thus, we see that mufflers can be fitted to new locomotives for less than a 1% increase in cost, and a retrofit program for mufflers is practical inasmuch as no locomotive has been identified that would be unduly difficult to retrofit.

Mufflers that produce 5 to 10 dB(A) of exhaust muffling are currently feasible. It is important that a muffler be designed to give as good muffling at idle as at full power, since locomotives idle much of the time. Unless other noise sources on the locomotive are also treated, the net locomotive quieting will be only about 6-dB(A) due to contributions from these sources (see Table 4-4).

Mufflers could be developed and ready for production by 1 January 1976. The manufacturers have sufficient capacity to produce the mufflers required.

Cooling Fan Modification

The next contribution to locomotive noise that may be treated is the cooling fan. This component is essentially aerodynamic noise resulting from the air movement created by the fan. Methods of treatment include increasing the diameter of the fan, adjusting clearances between blade and shroud, and varying the pitch of the blade. Although fan modifications are feasible, the application of fan retrofitting has not been developed for locomotives. Further, the impact of such a requirement could not be assessed with regard to cost and the effect of the total noise.

Engine Shielding

The vibrations of the engine casing is a significant component of the total locomotive noise. On a limited basis, work has been done to reduce the noise from this source by adding acoustic panels to the engine, stiffening the engine casing, and using sound-absorbing materials. This technique has not been developed to the extent that it could be applied to locomotives at this time.

Wheel/Rail Interaction

Although a less significant component of the total noise at low speeds, wheel/rail noise becomes significant as speed increases. In order to reduce this noise wheel flats can be eliminated, welded rail can be used, and rail can be grinded. These measures, however, allow only a certain degree of reduction and speed must be reduced for further reduction. The Department of Transportation is currently sponsoring research into the mechanism by which wheel/rail noise is generated.

Noise Abatement via Operational Procedures

In addition to applying noise abatement technology, there are a number of ways of reducing locomotive noise by changing operational procedures. These may be effective and practical noise abatement measures in certain situations, but they cannot be required on a general basis. They are discussed here only as being possible and are not necessarily being suggested as recommended noise reduction techniques.

Parking Idling Locomotives Away from Residences

One of the most frequent complaints about railroad noise is that locomotives are left idling overnight. Railroads are reluctant to shut down locomotives because (1) shutting down and starting locomotives require a special crew, (2) engines do not contain any antifreeze in their cooling systems and would have to be heated in cold weather, and (3) locomotive engines are likely to leak cooling fluid into the cylinders, which could damage an engine on starting if precautions were not taken to drain it. Therefore, locomotives are usually shut down only during their monthly inspection.

Railroads are sometimes rather careless about where idling locomotives are left; frequently they are parked on the edge of a rail yard close to residences. With a little effort, locomotives could be parked near the center of a rail yard where they would be less troublesome to neighboring homes.

Speed Reduction

The power needed to pull a train increases almost directly with speed, but the noise of a given locomotive increases very rapidly with speed. Thus, one could achieve some noise reduction by lowering the speed limit for trains passing through residential areas. For example, the throttle settings of the locomotives of passing trains would generally be lower, and hence the locomotive noise would be reduced. Further, other noise sources, such as wheel/rail noise, would also be reduced.

This noise reduction method may not be practical generally, except perhpas in special urban areas, since the net effect would be to slow the movement of train traffic. The cost to the railroads in terms of lower block speeds would be quite high.

A Ban on Night Operations

Many freight trains, particularly in the eastern United States, operate at night. Their noise is most disturbing at this time, since the background noise is lowest and people can be awakened from sleep. Thus, a significant impact on the annoyance of train noise can be made by banning nighttime operations. However, such a ban on night operations would frequently be impractical, since trains are scheduled for markets that open in the morning and the trains are loaded during the previous day. The resulting burden on the flow of interstate commerce could be extensive.

Use More or Larger Locomotives for a Given Train

One paradox emerged from the model of locomotive noise presented earlier. A large locomotive in a low throttle position develops less noise than a small locomotive in a high throttle position, even when the two develop the same horsepower. For example, a 3600-hp locomotive in throttle 4 generates 15 dB(A) less noise than a 2000-hp locomotive in throttle 8. Thus, a considerable noise reduction is achieved by using a 3600-hp engine to haul a train requiring only 2000 hp. Similarly, a 9 dB(A) reduction could be obtained by using four 3600-hp locomotives to pull a train that normally requires only two 3600-hp locomotives.

This noise reduction technique is considered to be highly impractical in general, since the extra haulage power required is enormous. However, this method could be used in some situations such as switching operations. Locomotive engineers could use low throttle positions rather than "gunning" the engine in throttle 8.

Noise Levels from Electric and Gas-Turbine Trains

There are other means of train propulsion, apart from diesel-electric currently in use on American railroads. Steam power is rarely used, except for romantic purposes, but all-electric and gas-turbine locomotives are becoming more popular, particularly in the Northeast corridor. Rickley, Quinn, and Sussan have measured the wayside noise levels of the Metroliner, Turbotrain, and electric passenger and freight trains. The levels at 100 ft are given in Table 4-7. All levels are below 88 dB(A) except for two Metroliner trains and the electric passenger trains. The speeds were 106 and 84 mph, respectively, and thus the wheel/rail noise is likely to dominate over the locomotive noise (see next section). Thus, in general, the non-diesel-electric locomotive noise is well below that of diesel-electric locomotives and the former are likely to comply with any regulation written for the latter. However, due to the limited data on noise emissions from all-electric and turbine trains separate noise emission standards could not be well defined for these specific types of locomotives at this time, but the proposed locomotive standards are applicable to these locomotives. When sufficient data are obtained, separate standards will be proposed.

TABLE 4-7

NOISE LEVELS FROM ELECTRIC AND GAS-TURBINE TRAINS

Train	No. of Cars	Direction	Speed (mph)	SPL [dB(A) 100 ft]
Metroliner	4	South	106	89
	4	South	110	89
	4	North	106	84
	6	North	110	84
	4	North	80	78
	6	North	84	80
Electric Pass	6	South	84	90 (wheel/rail)
Electric Freight (2 Locos)	3	South	49	88
Turbotrain	5	East	97	85
	5	West	91	85
	3	East	89	84
	3	West	104	88

Wheel/Rail Noise

Figures 4-3 and 4-4 show the results of many measurements of sound generated by the interaction between the wheels of moving railroad cars and the rails. The figures indicate that the A-weighted wheel/rail noise level varies as 30 log V, where V is train velocity.

Some of the sound levels in Figure 4-4 are significantly above the 30 log V expression. There are typically two reasons for this. First, flats on wheels can produce a very loud sound as the wheel rotates. Second, on sharp curves (less than 2000 ft radius), the flanges of the car wheels can rub against the rails ("flanging"), thus producing a high sound level.

The average trend of the data in Figure 4-3 can be summarized by the expression given in that figure. Although the expression is based on limited data, it should be useful for the prediction of wheel/rail noise levels until better information becomes available. The noise levels calculated from this expression apply to cars without hydraulic shock absorbers, moving over jointed rail that has not been ground smooth and that is not located on an elevated structure. Corrections must be applied to account for deviations from these conditions, as described in the 1972 DOT report.

The contributions of wheel/rail noise to overall train noise at 40 mph 100 ft away is 81 dB(A). The contribution to locomotive noise alone is 78 dB(A).

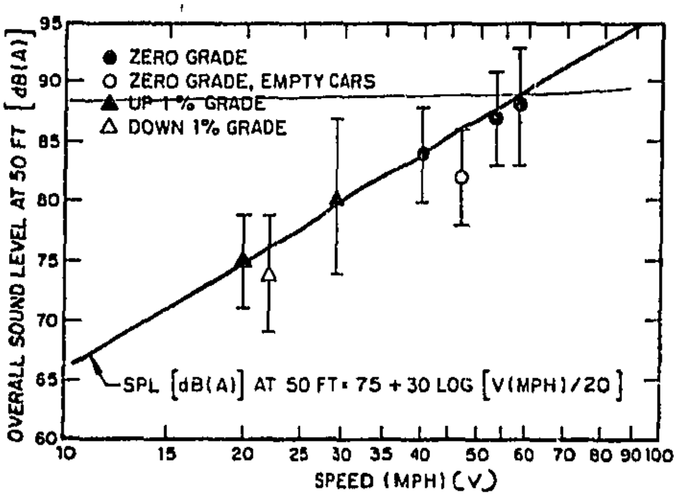

Figure 4-3. Wheel/Rail Noise Measured on Level Ground and on a 1% Grade

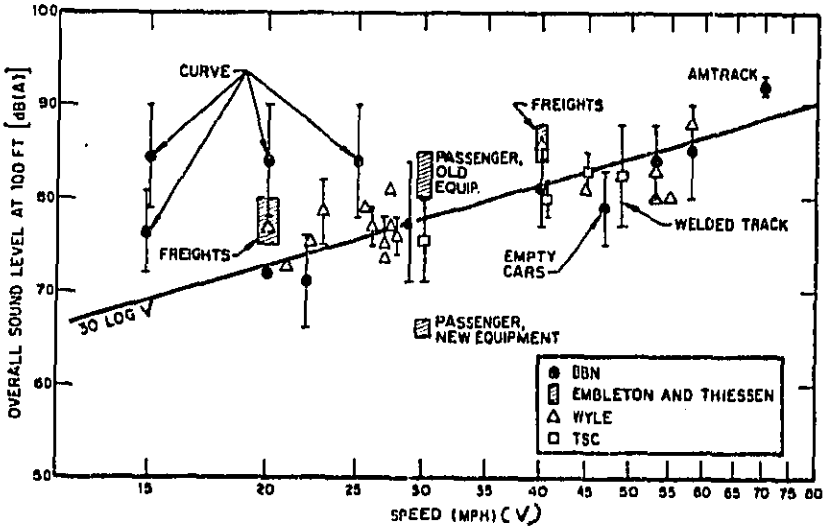

Figure 4-4. Measured Wheel/Rail Noise

The mechanisms by which wheel/rail noise is generated are not fully understood and more research is necessary in this area. For example, there is some evidence that wheel/rail noise is directional. This feature of the sound needs to be fully explored, because the directionality can probably be exploited in developing methods for controlling the noise. In the meantime, eliminating wheel flats, replacing jointed rail with welded rail, and reducing train velocity are three ways that wheel/rail noise can be reduced. In general, railroads try to avoid wheel flats, since they have other adverse effects, such as increased car maintenance and reduced safety. Jointed rail is currently being replaced, as needed, by welded rail. Train speed can also be reduced in some cases; however, this is an undesirable alternative from an operating standpoint.

Retarder Noise

Since hundreds of cars move through retarders in a 24-hr period in a typical yard, it would be difficult to analyze mathematically the motion of each car through retarders in order to predict retarder noise in general. However, a large number of cars can provide a basis for a statistical analysis of retarder noise. Figure 4-5 is an amplitude distribution of the results of measurements on more than 100 individual events of cars moving through retarders (BBN's procedures for measuring retarder noise are described in Appendix C-2).

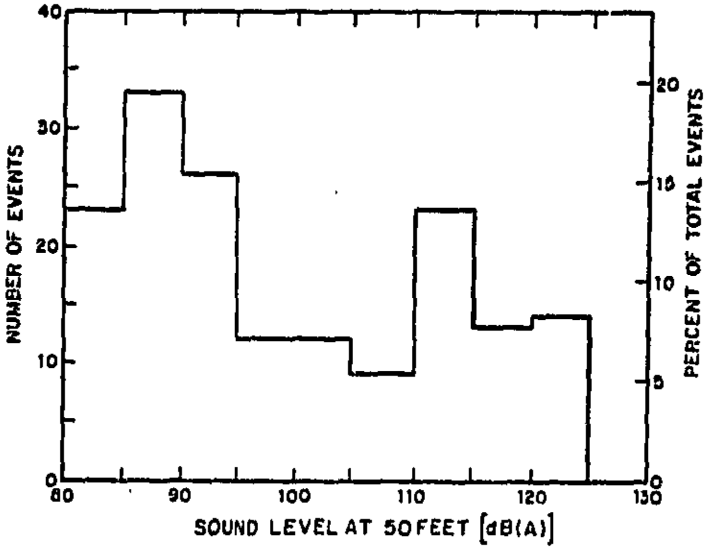

Figure 4-5. Retarder Squeal Amplitude Distribution

Although there have been some studies of the mechanisms that contribute to retarder squeal (Ungar, Strunk, and Nayak, 1970; Kurze, Ungar, and Strunk, 1971), the causes are not completely understood. Apparently, the noise levels are influenced by car type, car weight and loading, type of wheels, the structure and composition of the retarder, and the decelerating force that the retarder applies to moving cars.

Four methods can be used to control retarder noise: (1) a barrier to shield the retarders, (2) lubricating the retarder beams, (3) fitting ductile iron shoes on the beams, and (for inert retarders only) (4) using releasable inert retarders that allow a string of cars to be pulled through without noise-generating friction.* The advantages and disadvantages of the noise control methods are described below.

Barriers. A barrier 17 ft high gives 20 dB of attenuation 50 ft away relatively inexpensively—$50 to $70 per linear foot for cement block with absorber. However, installing a barrier requires space beyond the retarder, which may interfere with gas lines, electrical cables, switch heaters, and gas regulators.

Lubrication. The only advantage of retarder beam lubrication is in its noise-reducing capability. Lubrication causes an appreciable loss in retarding capability at a time when there is a trend toward bigger, heavier cars, which require more retarding power. The lubricant itself can be a disadvantage, because it is slick underfoot, is a possible fire hazard (although perhaps nonflammable glycerine can be substituted for oil), and leaves a coating of oil on the wheels, which could reduce braking ability.

Ductile Iron Shoes. Again, the only advantage seems to be in noise reduction. The shoes also cause an appreciable loss in retarding ability, and they wear quickly.

Releasable Inert Retarders. In addition to their capability of reducing noise, releasable inert retarders do not wear as quickly as other types of inert retarders. Their disadvantages lie in the release mechanisms: manual release is time-consuming and difficult in icy weather; automatic release is expensive because it requires a power source and controls.

Car-Car Impact Noise

The time histories of car-car impact noise illustrated in Figure 4-6 show some features of the physical phenomena that accompany car-car impact. The initial impact of the car couplers causes a "crack," as illustrated by the sharp rise in sound level in both parts of the figure. The high-frequency portion of the mechanical energy fed into couplers often excites an entire car body. The second time trace in the figure shows how, as the resulting vibrational energy decays exponentially, the radiated noise falls off proportionally. The time trace for a tank car hitting two loaded flat bed cars shows the noise sometimes generated by secondary impacts as cars pull away from each other

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*The first three methods are being tested by the Burlington Northern Railroad.

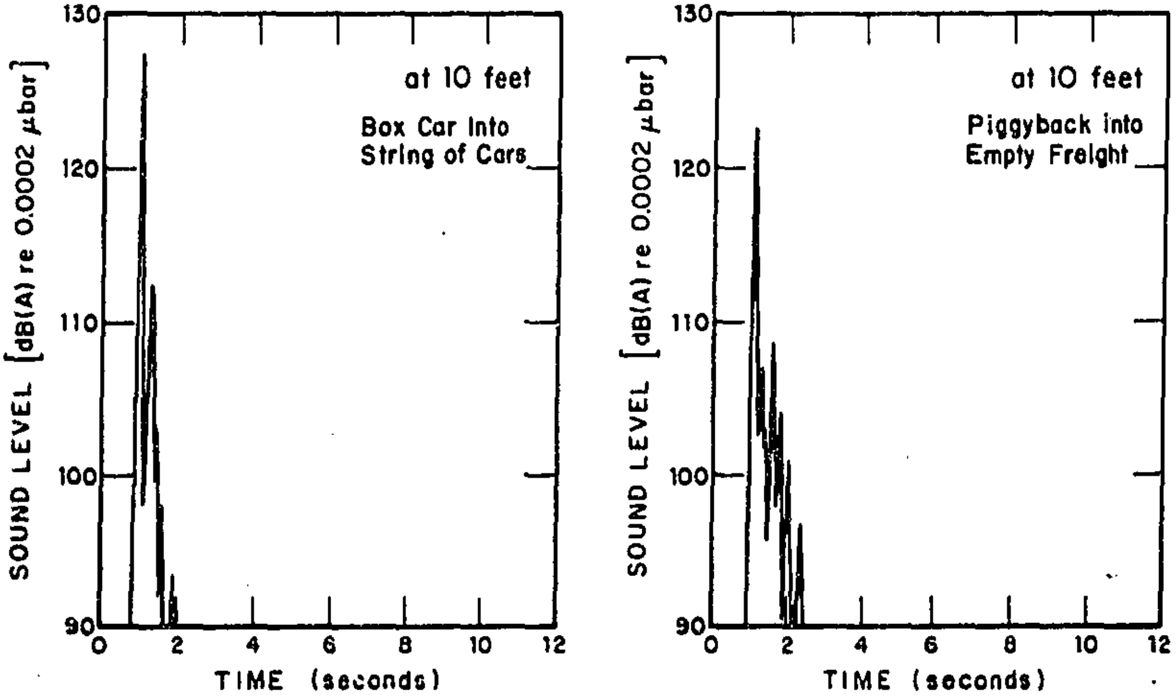


Figure 4-6. Car-Car Impact Noise Time Histories

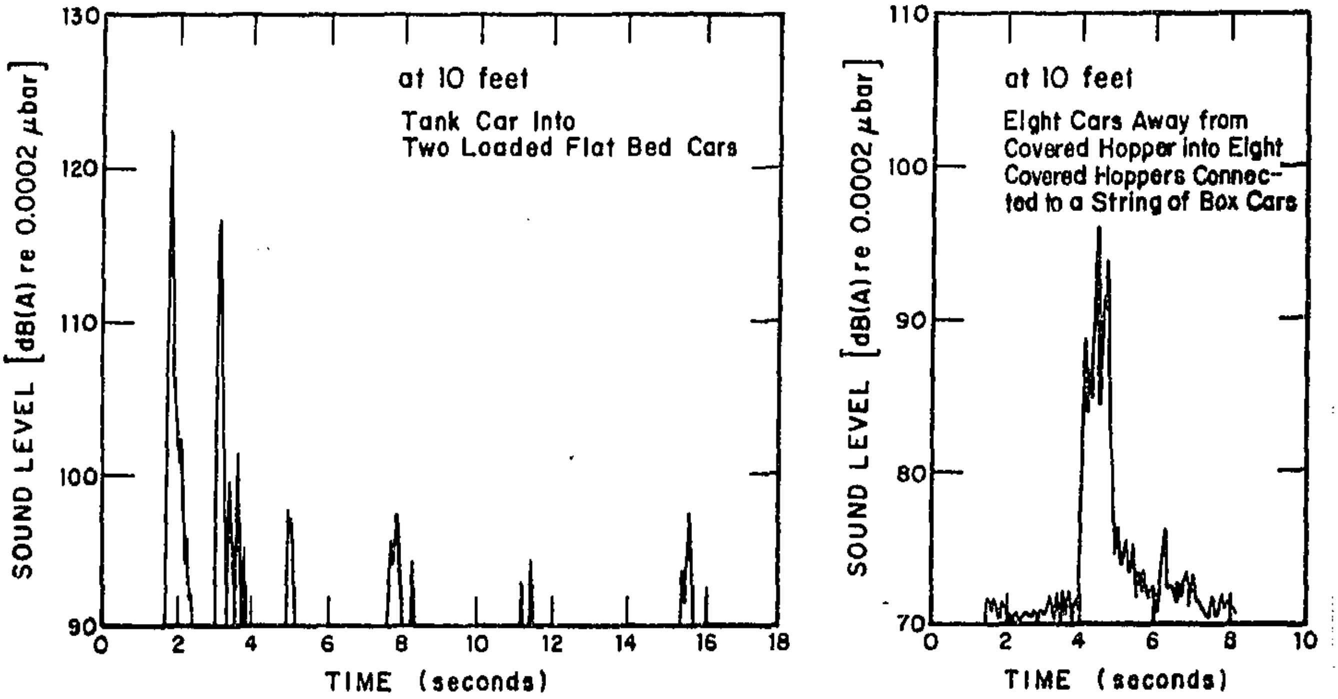


Figure 4-6. (Cont.)

and coupler slack is subsequently taken up. The time trace for the noise measured eight cars away from a point of impact shows how the energy from an impact can propagate along a chain of cars.

Warning Devices

This source of noise includes bells, horns, and whistles, which are sounded to warn pedestrians and motorists that a train is approaching a grade crossing. The noise level at 50 ft due to either a horn or a whistle is 105 dB(A) ± 10 dB(A). Of prime consideration in addressing these sources of noise is the measure of safety that they provide; however, the true safety value of these devices has not been conclusively assessed to date.

Methods of noise abatement for warning devices have not been fully evaluated. Some localities have required that the devices not be sounded, while others have required just the opposite. Various alternatives for controlling their noise include requiring reduced levels, specifying directionality, or limiting the times and areas in which the devices should be sounded.

Public Address Systems

Although the frequency of occurrence of noise from loudspeakers in railroad yards is sporadic and unpredictable, the level of the noise from speakers is comparable to the level of noise from other sources in the yards (see Figures 8-9 and C-1-6). Figure C-2-1 shows that many loudspeakers sometimes are scattered over a yard. Where abatement is desired or necessary, more speakers could be strategically located so that less volume is necessary, or railroad yards could follow the recent trend to switch to radio communication for certain types of communication.

Maintenance and Repair Shops

The noise from shops comes mainly from running the engines of stationary locomotives. Locomotive noise is described in Section 4. Other noises from maintenance and repair are overshadowed by the noise from retarders, car impacts, and locomotives moving about the yard. If controls are applied to noise from locomotives, car impacts, and retarders, that part of shop noise not due to locomotive engines may emerge as a significant part of the remaining noise.

Refrigerator Cars

These are railroad cars used to transport freight that requires refrigeration. It is necessary for the cooling equipment to operate continuously when the car is loaded, and also when the car is empty but a load is anticipated. This cooling equipment usually contains an unmuffled diesel engine to drive a compressor. These engines are similar in size and performance to engines used in other applications in a muffled configuration. It is believed that the muffler industry could supply the additional muffler requirement for rail refrigerator cars. However, application consideration would also have to include space availability and installation and replacement costs.

The maximum noise level from this source is approximately 75 dB(A) at 50 ft (Wyle Laboratories, 1973). When a train is moving, the noise levels emitted from a refrigerator car cannot be distinguished from overall train noise; however, if the train stops or if the cars are held over, the continuous operation of the compressor engine is a source of undesirable noise.

REFERENCES TO TABLE 4-2

1. R. A. Ely, "Measurement and Evaluation of the Impact of Railroad Noise Upon Communities," BBN Report No. 2623, August 1973.
2. E. K. Bender and R. A. Ely, "Noise Measurements In and Around the Missouric Pacific Centennial Yard, Fort Worth, Texas," BBN Report No. 2648, October 1973.
3. Electromotive Division of General Motors, presentation to American Association of Railroads, August 8, 1973.
4. General Electric, presentation to American Association of Railroads, August 8, 1973.
5. J. W. Awing and D. B. Pies, "Assessment of Noise Environments Around Railroad Operations," Wyle Laboratories Report WCR-73-5, July 1973.
6. E. J. Rickley, Department of Transportation, Transportation Systems Center, unpublished data.
7. M. Alakel, C. Malme, M. Rudd, Bolt Beranek and Newman Inc., unpublished data.

SECTION 5

SUMMARY OF WHAT THE PROPOSED REGULATIONS WILL REQUIRE

"APPLICATION OF BEST AVAILABLE TECHNOLOGY TAKING INTO ACCOUNT THE COST OF COMPLIANCE"

Section 17 of the Noise Control Act requires that the proposed regulations . . . "reflect the degree of noise reduction achievable through the application of the best available technology, taking into account the cost of compliance." For this purpose, "best available technology" is defined as that noise abatement technology available for application to railroads which produces meaningful reduction in the noise produced by railroads. "Available" is further defined to include:

1. Technology that is currently known to be feasible.
2. Technology for which there will be a production capacity to produce the estimated number of parts required in reasonable time to allow for distribution and installation prior to the effective date of the regulation.
3. Technology that is compatible with all safety regulations and takes into account operational considerations, including maintenance and other pollution control equipment.

The "cost of compliance," as used in the proposed regulation, means the cost of identifying what action must be taken to meet the specified noise emission levels and the additional cost of operation and maintenance. The cost for future replacement parts was also considered.

As discussed in Section 4 of this report, the only source of railroad noise to be regulated by the Federal government at the present time is trains. Therefore, the following pages will discuss the noise abatement technology for trains, in view of the statutory requirements and interpretation presented above.

Train noise is composed of locomotive noise and car noise. The latter is primarily the result of wheel/rail interaction. The locomotive noise is composed of noise from the engine exhaust, casing, cooling fans, and wheel/rail interaction. The technology for treating casing, fans, and wheel/rail noise is in the early development and research stages and thus not "available" for application at this time. However, at the present time, the technology for exhaust silencing has been found to be "available." Further, the locomotive noise is dominated by the engine exhaust noise and, therefore, the application of exhaust muffler technology is the most effective initial step to require for locomotive noise abatement. The consequences of establishing a standard that would require modification of engine casing, cooling fans, and wheel/rail interaction have not been assessed in detail. It is clear, however, that without first reducing exhaust noise treatment of these components would result in little or no noise reduction. Muffler technology is well known, and its application to locomotives has been assessed (see Section 7 of this report). The costs and effects have been predicted and in the judgment of the Agency constitutes the "applications of best available technology taking into account the cost of compliance."

LEVELS OF TRAIN NOISE CONTROL

In this section, we discuss noise levels for locomotives and cars that can reasonably be reached with appropriate maintenance of existing equipment and by applying the best available technology.

Locomotive Noise

As discussed in Section 4 of this document, locomotive noise is dominated by the exhaust of diesel engines, which operate at eight possible speed and power output levels. One way to ensure environmental noise control would be to limit the noise at all of these throttle settings; however, this could lead to cumbersome enforcement practices. For ease of enforcement, permissible noise could be specified at the throttle setting with the most noise–throttle 8. However, this approach may lead muffler manufacturers to design mufflers that are tuned to the engine speed corresponding to that throttle setting. Such mufflers could be very effective at the design setting and ineffective at other settings. Obviously, this would defeat the purpose of a locomotive regulation.

A compromise solution is to control locomotive noise at two conditions: idle and full power. Idle and full power apply to frequently used throttle settings. Specifying two throttle settings will probably preclude the design of specially tuned mufflers. Rather, we anticipate mufflers that will be uniformly effective at all throttle settings.

Although it is unrealistic to assume that mufflers can be designed, fabricated, and installed on locomotives the moment a regulation is promulgated, it is not unreasonable to hold noise at the level of existing, well-maintained equipment. Data, for locomotives at throttle setting 8, indicate that locomotives do not exceed 93 dB(A) at 100 ft. Likewise, data indicate that locomotives can be expected not to emit more than 73 dB(A) at 100 ft. Accordingly, the following levels have been identified as indicative of present noise emissions:

Idle	73
Overall Maximum	93

Section 4 indicates that mufflers capable of reducing exhaust noise by 10 dB(A) are feasible. Depending upon the relative contribution of the exhaust noise to the dominent sources of locomotive noise, this reduction may produce a 4 to 8 dB(A) reduction in the total noise (see table 4-5).

It is believed that the noisier locomotives have a higher exhaust noise component and, therefore, may achieve greater overall reduction in total noise by reducing exhaust noise. When exhaust noise is less dominant, smaller reductions in total noise will result. However, in this case, overall noise seems to be initially lower. Based on the considerations of limited empirical data, a reduction in overall noise of 6 dB(A) for the noisier locomotives is reasonable. Accordingly, the application of an exhaust muffler can be expected to permit all locomotives to achieve the following levels:

Idle	67 dB(A)
Overall Maximum	87 dB(A)

The exhaust noise is primarily a function of the diesel engine horsepower and the method of engine aspiration. Rootes blown engines would have higher exhaust noise than an equal size turbocharged engine. Also, a larger engine has higher exhaust noise than a smaller engine if the aspiration is the same.

However, the larger engines are generally turbocharged, while the small engines are rootes blown. This leads to a partial cancellation of the effect of power and aspiration on the exhaust noise. It may be feasible in the future to establish separate standards for different types of locomotives, depending upon power or method of aspiration. This is not possible with the present data, however.

Section 4 also shows that muffler manufacturer could supply the needed hardware after approximately 2 years for design, development, and testing. Allowing another 2 years for installation (see Section 8 of this document for a discussion of installation costs), a 4-year program for completion of muffler retrofit appears reasonable.

Rolling Stock Noise

Noise from rolling stock other than locomotives is summarized in Figure 4-2. The levels illustrated there never exceed 88 dB(A) when measured at 100 ft for trains traveling less than 70 mph. Accordingly, to prevent increased noise from inadequate maintenance a regulation of 88 dB(A) at 100 ft would be appropriate for trains traveling at less than 70 mph and 90 dB(A) at 100 ft at speeds above 70 mph.

SECTION 6

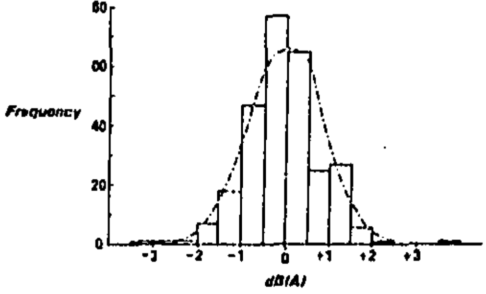
ENFORCEMENT CONSIDERATIONS

To be effective, a regulation must be easily enforceable. Here we consider several factors of enforcement, including measurement uncertainties and the feasibility of measuring locomotives under various conditions.

Measurement Uncertainties

When making sound measurements, the level of accuracy is never as high as that achieved with electrical, distance, or frequency measurements. An example of the scatter obtained with a large number of acoustic measurements on nominally identical automobiles was reported by Ratering (1973) when measured in accordance with an approved standard (SAE J986a). (Similar data do not exist for rail vehicles.) Most of the results lie within ±2 dB(A) of the mean. On a linear scale,

HISTOGRAM AND NORMAL
PROBABILITY CURVE FOR
277 J986a PASSBY TESTS



however, this is a spread of +60%, –35%. This scatter arises from the number of variables and uncertainties that can affect a particular acoustic measurement: the accuracy of the meter, the personnel involved, the test site, and the meteorological conditions. The effect of each of these is discussed below.

Uncertainties Due to Meters

A standard governing the accuracy of sound level meters is contained in the American National Standard, no. S1.4-1971. This specifies four types of sound level meters.

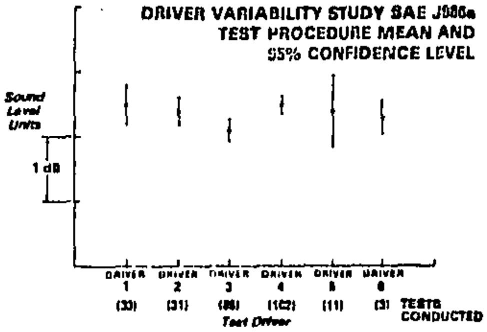
Type 1 – Precision
Type 2 – General Purpose
Type 3 – Survey
Type S – Special Purpose

The Type 1 meter is recommended for certification purposes and the Type 2 meter for enforcement purposes. The tolerances of these types of instruments are specified in American National Standards Institute S1.4 - 1971, "Specifications for Sound Level Meters."

In addition, the sound level meters are calibrated with acoustic calibrators that possess a finite uncertainty.

Uncertainty Due to Personnel

There will inevitably be variations in the measurements of a sound level due to the human element in the taking of measurements. Generally, there will be two people involved: one to drive the train and the other to read the sound level meter. The driver will do his best to operate the train under the same conditions each time, but inevitably there will be slight differences in the state of tune of the engine and rattles in the bodywork. Measurements have been reported by Ratering (1973) on the variability of sound measurements on the same truck on the same site with different drivers. The results are shown in the accompanying chart. (J366a is a standard Society of Automotive Engineers method for truck noise measurement.) It will be seen that an uncertainty of ± 1/2 dB can result.



Similarly, variations are obtained with different people reading a properly calibrated sound level meter. The table below lists seven different measurements of the *same* pass by of a *lawn mower.*

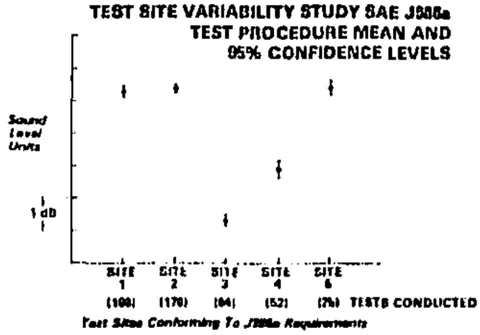
VARIATIONS IN NOISE LEVELS OBSERVED AT 50 FT

Observer	1	2	3	4	5	6	7	Average	Range
Level, dB(A)	70	71	71	71.5	71	72	71.5	71.1	2.0

Since sound pressure fluctuates due to its statistical nature, the needle of the sound level meter fluctuates and different people tend to average it differently. Hence, they obtain different readings.

Uncertainty Due to Test Site Conditions

Inevitably, sound measurements will be made at different test sites and this in itself gives rise to uncertainty in the sound measurements. An example of the variation to be expected for automobiles, reported by Ratering (1973), follows.

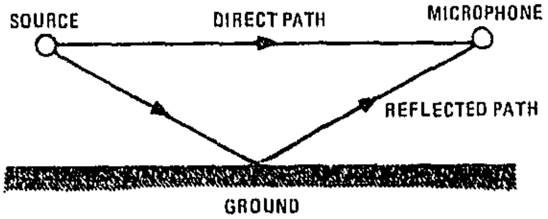


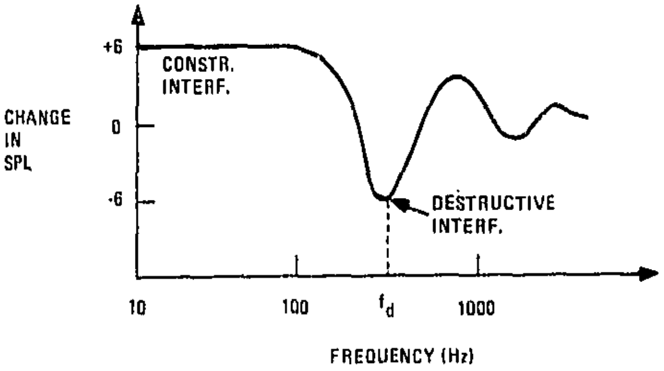
A total spread of about ±2 dB was observed, whereas the uncertainty at a particular test site was only about ±1/4 dB. A similar result was reported by Ringham and Staadt (1971) where a spread of ±1-3/4 dB was observed:

TEST SITE SOUND LEVELS

SITE 1	IH PROVING GROUND TEST PAD	87-1/2 dB(A)
SITE 2	ACCEPTABLE SAE J-366 TEST SITE	87-1/2 dB(A)
SITE 3	GRASS-COVERED SURFACE	86 dB(A)
SITE 4	GRASS AND LOWERED MICROPHONE LOCATION	85-1/2 dB(A)
SITE 5	GRASS AND 3-FT DITCH	86 dB(A)
SITE 6	6-8 IN. CURB	88 dB(A)
SITE 7	BLDG. ACROSS STREET, FENCE BEHIND MICROPHONE	89 dB(A)
SITE 8	CURB, BLDG., STONE WALL, GRASS	89 dB(A)
SITE 9	PARKING LOT – BUILDINGS ON 3 SIDES	89-1/2 dB(A)

This variability is caused by reflections, primarily from the ground but also from nearby buildings. The measurement specifications generally require any building to be at least twice as far from the observer as the sound source he is measuring. Then the maximum error that could be expected from a broadband sound source would be +1/2 dB. Ground reflections are a much more important source of variation than buildings. The ground may consist of an absorbent surface like grass, or a hard surface like asphalt. The sound reflected from the ground will interfere, either constructively or destructively, with the directly received sound. Constructive interference can give up to a 6-dB increase in sound pressure lvel. Destructive interference can give up to a 6-dB decrease in level over a one-third octave band. These effects depend on the difference in path length and on the sound absorption characteristic of the reflecting surfaces.





The change in the measured spectrum, shown above, is for a hard surface. At low frequencies it increases by 6 dB; at the frequency for destructive interference, f_d, it [illegible] it oscillates until at high frequencies there is no change. [illegible] the ground, like railroad locomotives, f_d is generally 200-300 Hz at normal measuring distances. Hence, effects of several dB(A) are observed on the overall A-weighted sound pressure level.

Uncertainties Produced by Meteorological Conditions

The atmospheric humidity, wind, and temperature can all have an effect upon propagation of sound through the atmosphere and hence upon sound levels measured. However, at a distance of 100 ft these effects are generally small.

Humidity in the air causes absorption of sound. Typically, at 2 kHz there will be about 0.4 dB absorption over 100 ft. This absorption is less at lower frequencies and greater at high frequencies.

Wind and temperature gradients have the effect of refracting (i.e., bending) sound waves so as to produce focusing or shadowing. On a hot day with an upwind the sound will be refracted away from the ground, giving an apparent decrease in sound level. Downwind, the sound is refracted downward, giving an increase. However, according to Kurze and Beranek (1971) no extra attenuation is to be expected at distances of less than 250 ft and hence these effects are not likely to be significant.

One secondary effect of the wind is to induce fluctuations in the observed sound pressure level, without affecting the mean value. Fluctuations of ±2 dB can be expected in a 10-mph wind. This will not produce any bias in the results, but it will make the sound level meter more difficult to read.

Measurements on Load Cells

The most repeatable and controllable tests of locomotive noise can be conducted on a load cell. A load cell is simply a bank of electrical resistors connected to the alternator output of a stationary locomotive. While connected, the locomotive engine can be operated at all throttle settings, duplicating conditions met in pulling a train. Only the wheel/rail noise source is not measured by this technique. However, this omission is not a serious defect since wheel/rail noise of present locomotives is dominated by the exhaust noise component.

There are likely to be certain costs, presently unknown, associated with load-cell measurements. Principally, it is not known which railroad shops would implement retrofit, whether they have load cells available, and what the costs of load-cell installation would be.

Measurements of Passing Trains

The enforcement technique that interferes least with railroad operations but the one that is also among the most imprecise and noncomprehensive is wayside measurement of passing trains. There are substantial difficulties associated with site selection, scheduling, uncertainty of operating variables, and extraneous noise sources.

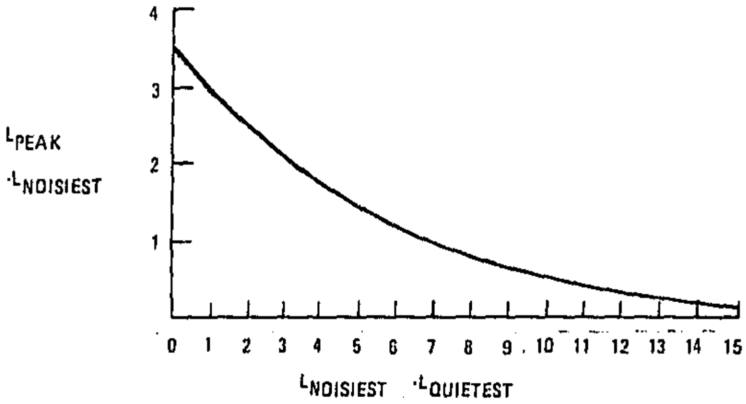
Site selection along a railroad line always presents difficulties. Sites should be selected so that effects beyond the reasonable control of the railroads do not lead to measured noise levels that improperly indicate the sound output of the locomotive. For example, reflections of sound from buildings, embankments, or other obstacles would corrupt a noise measurement. Similarly, excess sound absorption by ground cover or shielding by terrain or structures would degrade measurements.

Also, it would be inappropriate to trespass on private property for purposes of noise measurements.

Scheduling is difficult for several reasons. First, the average railroad line in the U.S. carries only about six to eight trains in a 24-hour period. Accordingly, inspectors would have to restrict themselves to conducting measurements on only the most heavily traveled routes and, even then, would expect to spend a good deal of time waiting for trains. Furthermore, a random sampling of trains on heavily used routes will result in the measurement of a segment of the locomotive population, with certain locomotives being measured repetitively at different times, and others measured not at all.

Uncertainty of locomotive operating variables has a substantial impact on enforcement. Throttle setting, for example, strongly influences locomotive noise. The difference in radiated sound between half power (throttle 4) and full power (throttle 8) is about 10 dB(A). Since an inspector at the wayside would not know the locomotive throttle setting, a standard would have to be based on the throttle 8 (i.e., the noisiest) operating condition. Limited existing data indicate that road locomotives operate at throttle 8 less than half the time they are pulling a train. Accordingly, roughly half of the locomotives would be measured at off-peak conditions. Furthermore, it would be a simple matter for a locomotive engineer to reduce the throttle setting or blow the locomotive horn if he were to see a wayside inspector. (A requirement for open space around the microphone would make the inspector quite visible.) Either tactic would invalidate measurements.

Another difficulty associated with wayside enforcement is that locomotives often operate together, all contributing to wayside noise. The accompanying chart illustrates how three locomotives, the center of which is noisier than the other two (which are of equal level), affect peak noise levels at 100 ft. The ordinate represents the difference between the peak sound pressure level, L_{peak}, and the level $L_{noisiest}$ of the noisiest locomotive. The abscissa indicates the difference between the sound pressure level of the noisiest locomotive, measured alone, and that of the quietest locomotive, $L_{quietest}$ measured alone. If all locomotives are equally noisy, together they will generate a peak level 3.5 dB higher than the level of a single locomotive. As the difference between the noisiest and quietest increases, the peak noise level approaches that of the noisiest locomotive. In selecting tolerance allowances for combined locomotive passby tests, great care must be taken to minimize the possibility for utilization of noisy locomotives in a train that would not pass inspection alone but would pass inspection when used in combination with other, quieter locomotives.


$L_{PEAK} - L_{NOISIEST}$
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
$L_{NOISIEST} - L_{QUIETEST}$

SECTION 7

ECONOMIC EFFECTS OF A RETROFIT PROGRAM

INTRODUCTION

The imposition of a railroad muffler retrofit program will affect both the railroads and the industries that purchase transportation services. Minimal changes in transportation patterns may be expected as a result of a retrofit program since increases in cost per ton mile of freight moved are estimated to be fairly small.

In the case of the railroads, the impact is felt in the possibility of higher costs and decreased revenues. In the case of railroad users, possible adverse effects are increased freight rates and a decline in the frequency of service. The purpose of this portion of the study is to examine the possible magnitude of such effects; their consequences in terms of railroad viability and the transportation of commodities; and techniques by which severe adverse economic impacts might be avoided.

The study presented here relies on a number of information sources and makes a number of assumptions in the course of arriving at quantitative estimates of impact. Data on costs of materials and labor for retrofit program were obtained chiefly from muffler manufacturers and railroad personnel. Information on locomotive maintenance requirements was likewise obtained from the railroads. Operating and financial statistics for individual roads and the industry as a whole came from reports of the Interstate Commerce Commission. To project the ultimate economic effects of incurred costs, assumptions were required concerning future trends in railroad activity. In some cases for which a range of assumptions was possible, the alternative least favorable in terms of impact was chosen; in this sense, the analysis represents somewhat of a "worst case" approach. Wherever assumptions are made, however, they are substantiated to the extent allowed by existing data.

THE IMPACT ON THE RAILROAD INDUSTRY

General Impact

The engineering data gathered from discussions with various manufacturers and railroad operating personnel were used to estimate the direct cost of muffler retrofit by locomotive type and manufacturer. The differences in construction between switcher and road locomotives required that these be treated separately. The three categories of direct cost are mufflers, additional hardware, and labor. Since each make of locomotive is somewhat unique, it was necessary to make separate analyses of each type. The costs are shown in Table 7-1. The retrofit costs associated with the various types of locomotives are based on the designs of several common types, which make up about 90% of the population. For some locomotives, retrofit costs may be significantly higher than the figures shown here. This may be the case, for example, for several hundred units which, although originally conforming to one of the common designs, have been heavily modified during service so that their configurations now present difficult hardware problems to a muffler installer. Also, there are still about 1,000 older units, manufactured by Alco and Fairbanks-Morse and owned by a total of 22 railroads, the design of which may render muffler installation difficult. This discussion, therefore, assumes that such units will be retired from service during the compliance period (a fair assumption given the advanced age of most such locomotives.

The estimates of the direct cost of mufflers and additional materials were gathered from locomotive and muffler manufacturers; the sources of the data on required labor input were locomotive manufacturers, muffler manufacturers, and management personnel of selected railroads.

An hourly wage rate of $5.80 per hour was arrived at by taking total compensation of maintenance personnel as reported in annual ICC summaries and dividing by total hours worked.* Although this wage rate probably includes some overtime compensation, it may be an accurate

TABLE 7-1
MUFFLER COSTS* PER LOCOMOTIVE
(Source: Manufacturers' and Operators' Estimates)

Time of Installation	Locomotive Manufacturer and Type				
	GM Road	GM Switcher	GE Road	Other Road	Other Switcher
New Production	$3000 (RB) 2500 (TC)	$200 - 500	$1500	-----	-----
Muffler Only	1500	200 - 500	1500	1500	500 - 800
Additional Hardware	200 - 500	-----	1500 - 2500	1500 - 2500	-----
Labor @ 5.80/hr	464 - 1163	46	187	187	46
Total	$2164 - 3163	$246 - 546	$3187 - 4187	$3187 - 4187	$546 - 846
	(RB) = Rootes Blown (TC) = Turbocharged				

*See footnote on page 7-3 relating to high-retrofit-cost locomotives.

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*All railroad data presented in this section come from Interstate Commerce Commission, *Transportation Statistics in the U.S.* (1971) unless otherwise specified.

reflection of the true labor cost, since some retrofitting may be done at the overtime rate. We assume that the current mix of straight time and overtime will be used in the retrofit program.

No capital costs for maintenance facilities were assigned to the retofit program. Annual compensation statistics and discussions with the American Association of Railroads indicate that the roads have been generally cutting back their maintenance staff over the last decade, while not necessarily reducing the size of their plant.* Frequently, therefore, excess physical capacity would be available for a retrofit program. In an economic, although not necessarily an accounting sense, such excess capacity can be utilized at zero cost.

The next step was to determine how many of each type of locomotive are in service. The May 1973 issue of *Railway Locomotives and Cars* lists the make and horsepower of each locomotive in service by railroad. In most cases, the horsepower of the engine could be used to determine whether it is a switcher or road locomotive. General Motors (GM) produces both a 1500-hp switcher and a 1500-hp road locomotive, but because road locomotives outnumber switchers by about seven to one, we assumed all General Motors 1500-hp locomotives to be road locomotives. This biased the cost estimates upward by a small amount. Table 7-2 shows the distribution of locomotives by type and manufacturer both nationally and for each of the three ICC regions.

TABLE 7-2

DISTRIBUTION OF LOCOMOTIVES BY MANUFACTURER, TYPE, AND REGION
(Source: "Railway Motive Power, 1973," *Railway Locomotives and Cars*, May 1973)

Manufacturer and Type	Region			
	Total	East (29 Roads)*	South (8 Roads)*	West (22 Roads)*
GM Road	16,155	7,006	2,026	7,123
GM Switcher	2,811	1,462	304	1,045
GE Road	1,930	878	230	822
Other Road	1,737	1,052	289	396
Other Switcher	1,504	734	139	631

*Number of roads in each district obtained from ICC, *op. cit.* Other listings of roads may not tally with this one, due to varying methods of accounting for mergers, subsidiaries, etc.

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*Sources in the AAR state that this may not be the case for roads which have recently modernized their plants and which may have divested themselves of some unneeded facilities. In these cases, according to the AAR, the cost of installing or renting the needed plant and equipment may significantly increase retrofit costs. Unfortunately, precise estimates of capital stock in maintenance facilities do not exist.

Total direct cost of the retrofit program was obtained by multiplying the cost per locomotive by the number of locomotives.* This is given in Table 7-3 in terms of minimum and maximum costs for each region and for the entire nation.

TABLE 7-3

TOTAL DIRECT COST OF RETROFIT PROGRAM
(Millions of Dollars)

Region	Locomotive Manufacturer and Type					Total
	GM Road	GM Switcher	GE Road	Other Road	Other Switcher	
East						
max.	$22.160	$0.798	$3.676	$4.405	$0.621	$31.660
min.	15.161	0.360	2.798	3.353	0.401	22.073
West						
max.	22.530	0.570	3.442	1.659	0.534	28.735
min.	15.414	0.257	2.620	1.262	0.345	19.898
South						
max.	6.411	0.166	0.963	1.210	0.118	8.868
min.	4.386	0.075	0.733	0.921	0.076	6.191
National						
max.						69.263
min.						48.162

The annual direct costs in Table 7-4 were derived from Table 7-3 by dividing total cost by the number of years allowed to complete the retrofit program. In addition, the annual cost for 2- and 5-year compliance periods is shown as a percentage of the 1971 net operating revenue. It should be noted that we are assuming 2 and 5 years beginning at the time the muffler becomes available.

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*Normally, some locomotives would be retired during the compliance period and, therefore, would not incur retrofit costs. (Their replacements would presumably have been quieted at the factory.) This consideration has not been included here, because it is difficult to forecast replacement rates in the light of an endemic shortage of motive power such as presently exists. If we assume instead that past retirement rates (about 2000 units per year from 1965 through 1969) are cut in half due to the shortage of locomotives, this will result in 5000 fewer units needing muffler retrofit for a 5-year compliance period and 2000 fewer over a 2-year period. The total cost estimates projected above would then be high by about 20% and 8% for the two compliance periods, respectively.

TABLE 7-4
ANNUAL DIRECT COST OF 2- AND 5-YEAR RETROFIT PROGRAMS

Region	Total Direct Cost (thousands of dollars)				Cost as Percentage of Net Revenue			
	2-Year		5-Year		2-Year		5-Year	
	Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.
National	34,632	24,082	13,853	9,633	1.35	0.94	0.54	0.38
East	15,830	11,037	6,332	4,415	2.04	1.42	0.82	0.57
South	4,434	3,096	1,774	1,238	0.82	0.58	0.33	0.23
West	14,368	9,949	5,747	3,980	1.09	0.75	0.44	0.30

Generally, mufflers will not be available until 2 years after this regulation is promulgated, so that the 2-year program will not be completed until 4 years after promulgation, and the 5-year program until 7 years after promulgation.

It appears that the direct cost of a retrofit program will not constitute a significant burden on the railroads. Total direct cost is invariant with respect to compliance period, although annual cost is not. Annual cost is, therefore, probably a more relevant measure of the financial impact on the railroads.

The direct cost of retrofitting mufflers is only part of the total cost, however. If retrofitting requires that locomotives be taken out of service and if the railroads have no excess capacity with respect to locomotives, then there will be some loss of revenue. At present, most railroads are operating at full capacity. The shipments of grain to the Soviet Union have resulted in a high demand for rail cars and locomotives. The number of locomotives has decreased slightly from 1965 to 1973 (from 27,988 to 27,041) although total horsepower did increase from 52 million in 1971 to 55 million in 1973. It appears, therefore, that capacity has remained about constant or decreased slightly while demand has increased. It seems unlikely that the present high volume of grain shipments will continue beyond a year. Other factors, however, indicate that the current high levels of capacity utilization will probably continue into the future.

One of the developments that will tend to keep rail transportation at a high level of capacity utilization is the projected "energy crisis." A general fuel shortage would favor the railroads over other modes of transportation. An increase in coal output, which seems inevitable, would stimulate rail freight volume. Coal, because of its low value per ton, is hauled almost exclusively by rail.

A further impact of the fuel shortage will be to degrade the quality and cost of truck transport relative to rail service. Speed limits will induce delays and uncertainties in truck schedules. Fuel price increase will have greater adverse impact on trucks than on rail, since trucks use 3.2 times as much diesel oil per ton mile of freight. As a result, transportation demand will tend to shift from trucks to rail. The net effect of these considerations is to support the assumption that railroads will be operating at close to full capacity for the next 5 or so years. This means that locomotive downtime due to retrofit will result in lost revenues.*

The time lost may be reduced by scheduling retrofits during regular locomotive maintenance. Nationally, the average maintenance cycle is 4 years for an intermediate overhaul and 8 years for a heavy overhaul. The length of the cycle for an individual railroad is a function of locomotive

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*One way in which operators may overcome this problem is to buy new locomotives to take the place of those being retrofitted. Such a procedure would virtually eliminate the indirect cost associated with the retrofit. This is an option, however, only if the locomotive manufacturers can produce the extra units. At present, according to locomotive manufacturers, locomotive production is below demand even though production facilities are operating at full capacity. It is reasonable to assume that conditions of motor power shortage relative to demand for transportation will persist throughout the compliance period, resulting in lost revenue when units are removed for retrofit.

mileage. Table 7-5 shows the national average adjusted regionally to reflect different average locomotive miles per year. The maintenance cycle is shortest in the West where locomotives travel more miles per year and longest in the East where miles per year are lowest.

TABLE 7-5

AVERAGE MAINTENANCE INTERVAL BY DISTRICT (years)
(Source: 1971 ICC Statistics and Operators' Estimates)

Type of Maintenance	Regional Average Maintenance Interval (Years)*			
	National	East	South	West
Intermediate	4.0	5.5	4.0	3.5
Heavy	8.0	11.0	8.0	7.0

*These figures do not include the effects of deferred maintenance as practiced by some roads in financial distress.

An intermediate overhaul generally takes about 2 to 3 days, while a heavy overhaul takes about 14 days. The estimated time required to retrofit a muffler ranges from 3 days for a General Motors road locomotive to 1 day for a switcher. Table 7-6 shows the number of lost locomotive days "charged" to retrofit under different conditions. Line 1, for example, gives lost days by type of locomotive if the locomotive is taken out of service specifically for retrofit. One can see that there are no lost days for any type of locomotive if all retrofitting is done during heavy overhaul.

TABLE 7-6

DAYS LOST DUE TO RETROFIT
(Source: Manufacturers' and Operators' Estimates)

Basis of Retrofit*	Locomotive Manufacturer and Type				
	GM Road	GM Switcher	GE Road	Other Road	Other Switcher
If done by itself	3	1	2	2	1
If done during regular intermediate overhauls	1	0	0	0	0
If done during regular heavy overhaul	0	0	0	0	0

*Assumes no lost time due to travel to and from shop and no muffler retrofitting done during emergency repairs.

As is shown, the total lost locomotive time due to muffler retrofits depends on how many locomotives can be treated during the normal maintenance cycle. Table 7-7 shows the expression used to compute total lost days for each line or district. The first term represents the time lost by GM road locomotives undergoing intermediate overhaul. The remaining three terms account for time lost by those locomotives that will not be due for routine maintenence during the compliance period and which, therefore, must be specially called in for muffler retrofit. (Recall from Table 7-6 that, except for GM road locomotives, units undergoing intermediate or heavy overhaul will experience no extra time lost due to retrofitting a muffler.)

TABLE 7-7

EQUATION FOR TOTAL LOST TIME PER DISTRICT

$$
LT = \left.\begin{array}{l}
\left[N_{GM} \times \frac{1}{2T_m} \times Y \times 1 \text{ day}\right] \\
+ \left[N_{GM} \times \left(1 - \frac{Y}{T_m}\right) \times 3 \text{ days}\right] \\
+ \left[N_{GEO} \times \left(1 - \frac{Y}{T_m}\right) \times 2 \text{ days}\right] \\
+ \left[N_{SW} \times \left(1 - \frac{Y}{T_m}\right) \times 1 \text{ day}\right]
\end{array}\right\} \text{ for } \left(1 - \frac{Y}{T_m}\right) > 0
$$

$$
= \frac{1}{2} N_{GM} \times 1 \text{ day} \qquad \text{for } \left(1 - \frac{Y}{T_m}\right) \leqslant 0
$$

where Y = number of years allowed for retrofit
N_{GM} = number of GM road locomotives
N_{GEO} = number of GE and "other" road locomotives
N_{SW} = total number of switchers of all makes
T_m = time interval for "Intermediate" maintenance

The equation in Table 7-7 has been used to compute lost locomotive days for each region. These have been summed to give a national total. The figures are shown in Table 7-8. Two compliance periods are used to illustrate the decrease in lost time with a longer retrofit period. We see from the table that increasing the period from 2 to 5 years results in a decrease of the lost locomotive days per year by 70 percent.

A change in the compliance period affects only the number of lost locomotive days; the direct cost of the retrofit program does not change. If we take the total number of lost locomotive days resulting from a 2-year period and assign it the number 1, then the total number of lost days for a 3-year program is 0.76, the total of a 4-year program is 0.52, and the total of a 5-year program is 0.29. As the compliance period is lengthened, lost locomotive days decrease; thus, the indirect cost of the program decreases.

The calculations of lost locomotive days must be translated into dollar costs. A number of problems arise in calculating the value of a locomotive. First, should a distinction be made between road locomotives and switchers? It seems desirable to treat the transportation revenue earned by rail service as being earned by both road and switch engines, since the lack of either (if both are used to full capacity) would cause a reduction in service. We have therefore assumed that each has the same value per day.

Secondly, what value should be assigned to a locomotive day? If all roads are operating at full capacity, then removing a locomotive causes a daily loss of revenue amounting to the value of one locomotive day. A locomotive day is thus evaluated at the value of the average product. This technique is further justified in capital theory, which states that the value of a piece of capital is the present value of its discounted future stream of earnings, that is, the present value of the marginal product.

TABLE 7-8

LOST LOCOMOTIVE DAYS BY REGION AND COMPLIANCE PERIOD

Compliance Period	Lost Locomotive Days	Region			
		National*	East (29 roads)	South (8 roads)	West (22 roads)
2-year program	Yearly	00,048	9,252	2,143	6,378
	Total	34,096	18,504	4,286	17,048
5-year program	Yearly	2,044	1,129	203	712
	Total	10,220	5,645	1,013	3,562

*Locomotive days lost nationally is not the sum of the three regions, since the national was calculated using an average maintenance cycle and the regional was adjusted to reflect different utilization rates.

Given the conditions stated above, the value of a locomotive day was calculated by taking total transportation revenue and dividing by the total transportation revenue and dividing by the total number of locomotive days available. Table 7-9 shows these calculations nationally and regionally. Table 7-10 gives estimates of the indirect costs of a 2- and 5-year retrofit program by incorporating the lost locomotive days from Table 7-8 and the value of a locomotive day from Table 7-9. Note that the shorter the compliance period the larger the total indirect costs. This is a function of the increase in the number of lost locomotive days as the compliance period is shortened.

TABLE 7-9

REGIONAL ANNUAL REVENUE PER LOCOMOTIVE DAY

	Region			
	National	East	South	West
Total tranportation revenue (millions of $)	$12,417	$4,497	$2,121	$5,799
Transportation revenue per locomotive day ($)	1,251	1,186	1,256	1,304

TABLE 7-10

ESTIMATED LOST REVENUE DUE TO RETROFIT
(Thousands of Dollars)

Region	2-Year Program		5-Year Program	
	Per Year	Total	Per Year	Total
National	21,982	43,963	2,557	12,785
East	10,973	21,946	1,338	6,690
South	2,692	5,383	254	1,270
West	8,317	16,634	928	4,640

Table 7-11 arrives at the annual net retrofit cost by combining the direct and indirect costs and subtracting the reduction in operating costs that would occur as a result of a reduction in traffic. Cost reductions were determined from the ICC detailed accounts and include the following:

Account No.	Description
365	Dispatching Trains
367	Weighing, Inspection, & Demurrage Bureaus
368	Coal and Ore Wharves
371	Yard Conductors & Brakemen
373	Yard Enginemen
374	Yard Switching Fuel
382	Train Enginemen
383	Train Fuel
387	Trainmen
388	Train Supplies and Fuel
395	Employees' Health and Welfare Bureaus

The estimates of cost reductions used here are much lower than those used by the ICC.* They have claimed that 80 percent of costs are out of pocket or variable costs. This might be true if railroads were curtailing service in the face of falling demand. Variable cost may constitute 80 percent of total cost, but the situation dealt with here is an unplanned reduction in capacity in the face of full utilization of equipment. Under these circumstances, it seems unlikely that the railroads would curtail other operations but rather that they would attempt to offset locomotive shortages by changes in labor and equipment usage patterns. In addition, if there are adjustment costs and since the cutback in capacity is temporary, the railroads would be expected to respond differently from a situation in which the reduction was anticipated to be of longer duration. Table 7-12 gives the total net cost of the 2- and 5-year programs. Again, it points up the cost differential associated with different compliance periods. Much of the computer retrofit cost if the result of lost revenue to the railroads. Figure 7-1 shows the breakdown of annual cost into direct and indirect components for compliance periods of 2 to 5 years.

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*See U.S. Interstate Commerce Commission, Bureau of Accounts, *Explanation of Rail Cost Finding Procedures and Principles Relating to the Use of Costs.* St. 7-63, Washington, D.C., 1 November 1963 and U.S. Interstate Commission, "Rules to Govern the Assembling and Presenting of Cost Evidence." Docket No. 34013,321 I.C.C. 238 Order of April 16, 1962.

TABLE 7-11

ANNUAL NET COST OF RETROFIT
(Thousands of Dollars)

Direct Cost	National	East	South	West
2-year program				
max	$34,632	$15,830	$4,434	$14,368
min	24,082	11,037	3,096	9,949
5-year program				
max	13,853	6,332	1,774	5,747
min	9,633	4,415	1,238	3,980
Indirect Cost				
2-year program	21,982	10,973	2,692	8,317
5-year program	2,557	1,338	254	928
Reduction in Operating Costs				
2-year program	4,964	2,748	555	1,856
5-year program	597	335	53	207
Net Cost				
2-year program				
max	51,650	24,055	6,571	20,829
min	41,100	19,262	5,233	16,410
5-year program				
max	15,813	7,335	1,975	6,468
min	11,593	5,418	1,439	4,701

TABLE 7-12

TOTAL NET COST OF RETROFIT PROGRAM
(Thousands of Dollars)*

Compliance Period	National		East		South		West	
	Max	Min	Max	Min	Max	Min	Max	Min
2 years	103,300	82,200	48,110	38,524	13,142	10,466	41,658	32,820
3 years*	95,221	74,121						
4 years*	87,143	66,043						
5 years	79,065	57,965	36,675	27,090	8,875	7,195	32,340	23,505

*These represent linear interpolations of the 2- and 5-year programs.

The annual costs shown in Table 7-11 are best understood in the context of total operating revenue for each region. Table 7-13 shows that the eastern roads would pay a higher percentage of total revenue toward a retrofit program than would the other regions.

Annual retrofit cost as a percentage of net operating revenue* gives the best indication of the rail industry's ability to pay for a retrofit program (see Table 7-14). Retrofit constitutes a small percentage of net operating revenue both nationally and regionally. As we have seen earlier, however, the eastern railroads will pay the highest percentage of net revenue for the retrofit program. This partly reflects the fact that eastern roads as a group tend to earn less profit than roads in other regions.

TABLE 7-13

ANNUAL RETROFIT COST AS A PERCENTAGE OF 1971 TOTAL OPERATING REVENUE

Compliance Period	National		East		South		West	
	Max	Min	Max	Min	Max	Min	Max	Min
2 years	0.42%	0.33%	0.53%	0.43%	0.31%	0.25%	0.36%	0.28%
5 years	0.13%	0.09%	0.16%	0.12%	0.09%	0.07%	0.11%	0.08%

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*Net operating revenue is defined as transportation revenue minus variable transportation costs. Subtracting rents, taxes, and interest payments from net operating revenue gives net operating income, or profit from freight operations.

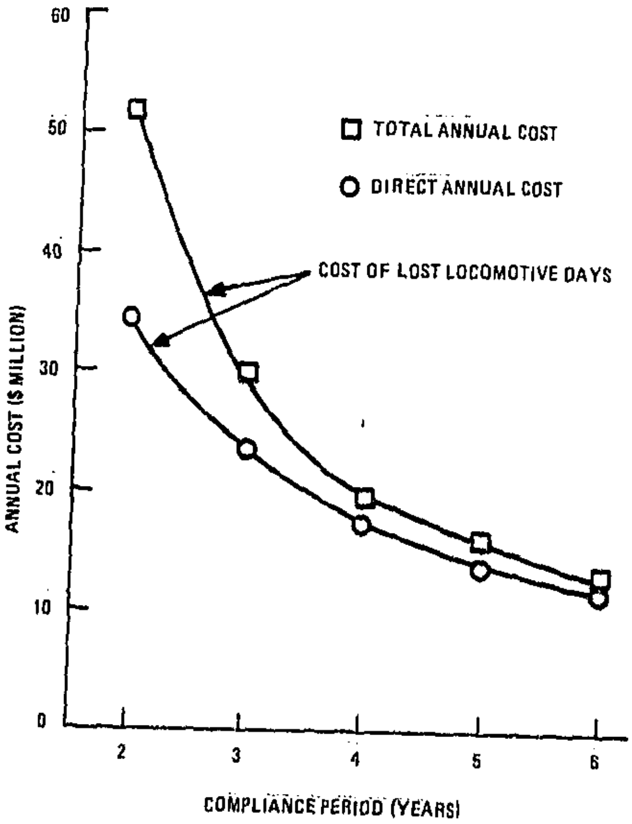

Figure 7-1. Cost of Retrofit Program as a Function of Compliance Period

TABLE 7-14

ANNUAL RETROFIT COST AS A PERCENTAGE OF 1971 NET OPERATING REVENUE

Compliance Period	National		East		South		West	
	Max	Min	Max	Min	Max	Min	Max	Min
2 years	1.96%	1.56%	2.48%	0.31%	1.22%	0.97%	1.58%	1.24%
5 years	0.60%	0.44%	0.95%	0.70%	0.38%	0.27%	0.49%	0.36%

Bankrupt roads constitute a special subset for which financial and operating problems are substantially different than for normal roads; these will be treated elsewhere.

In order to give a more detailed picture of the industry's ability to pay for retrofit program, program cost as a percent of net operating revenue has been computed for each Class I railroad (including bankrupt roads but excluding those with negative net revenues). Figure 7-2 shows how the railroads are distributed with respect to cost-to-net revenue ratio. The figure shows that the impact of a 2-year program is much greater than that of a 5-year program.

The Impact on Marginal Railroads

The adverse effects of extra operating costs is greater on firms in financial distress than those that are healthy. This is of concern in the case of the railroads, because a number of them face difficulties in maintaining profitable operations. It is important to estimate the number of railroads that may have trouble paying the cost of a retrofit program even though the magnitudes of the expenses involved in such a program are small relative to other expenses faced by the railroads. (For example, a 30 percent increase in the price of diesel fuel would increase operating costs by roughly $125 million.* This would represent from 2.5 to 12 times the annual cost of a muffler retrofit program, depending on the compliance period allowed.)

This section attempts to gauge the extent of the problem posed in paying for a retrofit program by determining how many railroads are in financial distress. This is done by computing, for each road, several financial ratios that are generally accepted as indicating the financial condition of a business enterprise. A summary of the number of roads with unfavorable values for each ratio is then given. This technique does not give a quantitative definition of which railroads cannot afford a retrofit program. At best, it gives a rank-ordering. The cutoff value that determines "financial distress" is arbitrary.

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*This figure is computed by using as a baseline the total cost of fuel for all Class I railroads in 1971, which was $417 million (ICC, op. cit.)

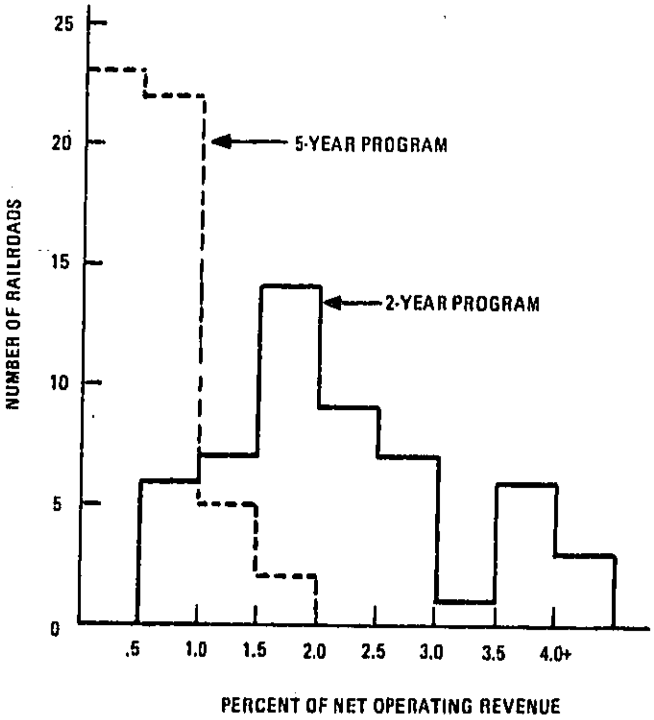

Figure 7-2. Distribution of Railroads by Retrofit Cost as a Percent of Net Operating Revenue for 2- and 5-year Compliance Periods. (Maximum Total Cost Assumed, Bankrupt Roads Included; Made with Negative Net Operating Revenue Excluded.)

The following financial ratios were computed:

a. Current assets/total assets
b. Operating ratio (operating expenses/operating revenues)
c. Total liabilities less stockholders' equity/total assets
d. Income after fixed charges/total assets
e. Retained earnings/total assets
f. Net income/total assets
g. Net income/operating revenue

All bankrupt roads are excluded from this discussion, which is concerned only with roads that have not been declared bankrupt but which may be in financial distress.

In most cases these ratios parallel those used by Edward Altman (1971). Ratios a and b are measures of the liquidity* of a railroad, while b, d, f, and g are measures of profitability and efficiency. Ratio c measures solvency.

With respect to ratio *a*, the analysis seems inconclusive. A large number of roads had ratios of current to total assets in excess of three standard deviations from the mean. This indicates that the distribution of values of this ratio did not approximate a normal distribution. This being the case, ratio *a* does not constitute a valid indicator of which roads may be in distress.

The analysis of ratio *e* (retained earnings/total assets) indicated that 14 railroads have negative retained earnings, while two have zero, showing that these roads lack liquidity. While internal financing may not be important in the rail industry, the negative retained earnings indicates that these roads are drawing down cash reserves.**

The most commonly used measure of profitability is operating ratio *b*, the ratio of operating revenue to operating expenses. Three roads have operating ratios greater than 1, indicating that expenses exceed revenue. An additional seven roads have operating ratios more than three standard deviations higher than the mean. Certainly the three roads and possibly some of the seven must be considered to be in an adverse position. Ratios *f* and *g* are similar measures, in that a road with a negative net income will have a negative ratio for both *f* and *g*. Six roads have negative net incomes. In addition, two other roads must be considered to be poor performers as measured by the ratio of net income to total assets (*f*).

Ratio *d* indicates that nine roads have negative income and two have zero income after fixed charges. These roads are unprofitable by definition. The ratio of total liabilities (less stockholders' equity) to total assets *c* appears to have also yielded inconclusive results. One road stands out as being extremely poor by this measure, and there are four other roads for which this ratio is greater than 1.

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*Liquidity is the ability of a firm to convert assets into cash.

**This may also represent an insufficient amount of funds allocated to depreciation.

A word of caution should be issued in the interpretation of any ratio that uses total assets. Under the "betterment" accounting procedure, total assets tend to be inflated. However, to the extent that this bias is uniform throughout the industry, it is possible to compare different roads. It is not possible to compare these ratios with other firms outside the rail industry.

Table 7-15 summarizes the above findings with respect to the named ratios. As was mentioned before, the table lists "worst performers" as indicated by each ratio, the cutoff point being rather arbitrary. More significant is Table 7-16, which shows how many of the railroads contained in the previous table appear under more than one ratio. Table 7-16 shows that 12 roads are in distress with respect to three or more indicators; it can reasonably be presumed that these 12, at least, could have difficulty in financing a retrofit program.

The Impact on Bankrupt Railroads

Of the 71 Class I line-haul railroads in the United States, seven are bankrupt: Boston and Maine, Central Railroad of New Jersey, Erie Lackawanna, Lehigh Valley, Penn Central Transportation Co., the Reading Co., and Ann Arbor. These seven railroads operate about 20% of the locomotives owned by Class I railroads in the U.S. Not surprisingly, the total cost of retrofit for these roads (see Table 7-17) is about 20% of the total cost for the entire muffler retrofit program.

These railroads will have difficulty financing the cost of a muffler retrofit program. There is no question that the financial positions of these roads are bad. All six have negative net income, and are currently meeting their deficits in part by drawing down cash reserves. Many of these roads are currently receiving some form of subsidy, and all are in default on interest payments, bonds, and/or taxes.

THE IMPACT ON USERS OF RAIL TRANSPORTATION

The effect of a muffler retrofit program may be felt by the railroads' users in either or both of two ways. First, the possibility exists that the railroads may try to recover their retrofit expenses through a rate increase. Second, the necessity to withdraw locomotives from service could result in reduced hauling capacity and a consequent decline in the quality of service. Either of these developments would tend to encourage some shippers to seek elsewhere for transportation services. This section examines the possible magnitude of these efforts.

The Effect On Railway Freight Rates

The ability of the rail industry to recapture the cost of a muffler retrofit program depends on the characteristics of the market it faces. The establishment of Amtrak and the low volume (and high price elasticity) of passenger service probably precludes the railroads from recovering any of the retrofit costs through increases in passenger fares; rather, increased revenues would be more likely to come from increasing freight rates.

TABLE 7-15

NUMBER OF RAILROADS IN UNFAVORABLE FINANCIAL POSITION RELATIVE TO EIGHT INDICATORS

(For Each Indicator, Railroads Listed in Order of
Increasingly Favorable Position)

Indicator	Number of Roads in Unfavorable Position
A. Current assets/total assets	Inconclusive
B. Operating ratio	4 roads' greater than 1 (expenses > revenues) 4 roads' between 1 and .85
C. Total liabilities (less stockholders' equity)/total assets	3 roads' greater than 1 2 roads' equal 1 2 roads' between .99 and .71
D. Income after fixed charges/ total assets	8 roads' negative 1 road's zero
E. Retained earnings/total assets	13 roads' negative 1 road's zero
F. Net income/total assets	4 roads' negative 4 roads' zero 2 roads' positive but less than .011
G. Net income/operating revenue	4 roads' negative 2 roads' zero 2 roads' positive but less than .031

TABLE 7-16

NUMBER OF RAILROADS DESIGNATED AS BEING IN FINANCIAL DIFFICULTY BY ONE OR MORE FINANCIAL INDICATORS

Number of Financial Indicators, N, in Table 7-15	Number of Railroads Appearing under N Indicators in Table 7-15
1	7
2	2
3	6
4	3
5	2
6	1

TABLE 7-17

NET COST OF MUFFLER RETROFIT PROGRAM FOR THE SEVEN BANKRUPT CALSS I RAILROADS

Length of Program	Annual Cost		Total Cost	
	Max	Min	Max	Min
2 Years	$10,569,000	$8,393,000	$21,139,000	$16,786,000
5 years	3,197,000	2,326,000	15,984,000	11,631,000

Freight rate increases must be approved by the Interstate Commerce Commission. Inquiries to the ICC indicate that the Commission places no *a priori* limits on the magnitude of rate increases that may be requested. It is entirely the railroad industry's prerogative to decide if requests for rate increases are to be submitted to cover the costs shown in Table 7-12. Any cost factor could form a legitimate basis for increasing rates to recover costs. Furthermore, the Commission is considering environmental aspects in its rate determination. As a result of litigation involving the environmental effects of various rate structures, the ICC has prepared several Environmental Impact Statements showing their concern.*

In summary, there are strong indications that the rate increases that may be requested by railroad companies to defray the costs of noise reduction would fall within the practice of the ICC. No *a priori* bias would be applied by ICC agents, and they can be expected to act with a positive attitude toward the objective of improving the quality of the environment.

To place the level of expenditure and possible freight rate increase in perspective, we can look at previous cost increases and subsequent rate increases. In the ICC report served 4 October 1972, in Ex Parte 281, a rate increase for railroad freight was authorized. The railroads claimed in their rate request that expenses had increased $ 1.312 billion from January 1971 to April 1972. The authorized rate increases were

National Average	3.44%**
East	3.60%
South	3.10%
West	3.44%

These increases, if fully applied, would have increased revenue by $426 million; however, the most usual case is that they are not fully applied. The industry estimates that only 85% or $349 million will actually be realized.***

Since the rate increase of September 10, 1972, costs have risen by $930 million. About 80% of this rise has stemmed from wage increases and increased payroll taxes. In light of these higher costs, in April of 1973 the railroads applied for a 5% rate increase. The maximum cost of the 2-year muffler retrofit program is about $51 million, which is only 5.5% of the $930 million cost increase that led to the request for a 5% rate increase. The rail industry claims that if the entire $930 million cost increase is to be recovered, it will require a 7.5% increase in rates.****

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*See ICC Docket, Ex Parte 281 and Ex Parte 344F, Supplement 927.

**The national average was calculated by using regional data.

***These figures come from estimates made by the rail industry. They assume that the elasticity of demand is zero—an unlikely situation. The question of elasticity is considered later in this section.

****Again, this estimate assumes that the elasticity of demand for rail service is zero. This is incorrect.

The amount of the recoverable costs and the attendant freight rate increase necessary will depend on the elasticity of demand for rail freight service.* The annual (maximum) retrofit costs for the 2-year program represent about 0.4% of 1971 freight revenue, while the 5-year (minimum) program represents only about 0.1% of freight revenue (see Table 7-13).

Data from Friedlander (1969, p.73) for 1961 have been used to calculate an overall rail freight demand elasticity of -0.7. Using this elasticity, we can estimate the increase in freight rates necessary to offset the increased costs. The freight increases are shown in Table 7-18. Also shown in the percent these increases would represent of the 1971 average rate per ton mile, which was $.01594.

TABLE 7-18

RATE INCREASE THAT WOULD ENABLE RAILROADS TO RECOVER RETROFIT EXPENSES

	Rate Increase (Cents per Ton Mile)	Percent of 1971 Average Freight Rate
2-year		
max	.0232	1.46%
min	.0184	1.15
5-year		
max	.0076	0.48
min	.0057	0.36

These rate increases must be interpreted carefully. They were calculated by using demand elasticities derived from 1961 data; since then a number of changes have taken place that would probably increase the elasticity of demand for rail service. First, the near-completion of the interstate highway system has improved the service rendered by trucks and has reduced operating costs. Second, the rise in interest rates has made the cost of holding inventories higher and might have made shippers more sensitive to other service characteristics, causing a downward shift in the demand curve and potentially increasing its elasticity. Third, shifts among the various commodity classes of freight might have resulted in an increase in the elasticity. For example, if the price elasticity of demand for rail service is higher for mineral ores than for manufactured products and if the share of mineral ores has increased relative to manufactured products, then the overall elasticity would have increased.

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*Elasticity of demand is the ratio of the percent rise in quantity demanded to the percent rise in price. An elasticity coefficient of -.1, therefore, indicates that a 10% price increase would result in a 1% decrease in demand.

We have attempted to make some estimates of the new elasticity, taking into account the shift in the distribution of commodities. The results should be interpreted only as tentative. We have used the 1961 elasticities for each commodity group but have weighted them by the 1971 commodity distribution.

Data from Friedlander (*op. cit.*, p. 73) have been used to obtain the following elasticities for the five major commodity groups:

Commodity	Elasticity
Agriculture	0.5
Animal products	0.6
Products of forests	0.9
Products of mines	1.2
Manufacturing and other	0.7

These figures represent the pre-1964 commodity classifications used by the ICC. In order to determine the current elasticity of demand, we used these commodity group elasticities and weighted them by the current distribution of freight within these groups. These weighting factors are as follows:

Commodity	Weight
Agriculture	.097
Animal products	.0002
Products of forests	.144
Products of mines	.420
Manufacturing and other	.387

To determine the distribution, it was necessary to take the current freight classifications and assign them to one of these categories.

The overall elasticity was calculated to be −0.953, significantly more than the estimate of −0.7 obtained from Friedlander's data. Even more interesting is the distribution of elasticities by district. To arrive at these estimates, it was necessary to assume that the rate per ton mile for each of the 1971 commodity classifications was equal for each of the three districts. Although this is not the case, we believe the errors to be quite small. The estimated elasticities are:

East	−0.99
South	−0.95
West	−0.83

These figures indicate that the eastern roads, which are in financial difficulty, would have the most trouble recovering the cost of a retrofit program. The western roads, which as a group are the most profitable, would recover the cost of a retrofit program most easily.

Given the current energy crisis, however, even this tentative analysis may not be valid. As discussed earlier (p. 3-7) railroads use less energy per ton mile of freight moved than trucks, pipelines, or airlines. As a result, railroads will be impacted less than these other competitive modes by increases in fuel costs.

It is not possible to predict accurately, at this point, the effect of any rate increases the ICC might grant to the railroads to recover the costs of a retrofit program. The possible effects of increased rates on demands for rail service are directly related to the current energy situation. If competitive modes of transportation (i.e., trucks, pipelines, and airlines) are more severely impacted by increased fuel rates, the fact that railroads increased their rates to cover the costs of a retrofit program might well be insignificant.

The Effect on Quality of Service

It has been shown above (see Introduction) that, in order to accomplish a retrofit program within a compliance period of 5 years or less, some locomotives would have to be withdrawn from service in addition to those undergoing maintenance by the usual schedules. The number of locomotive days taken up in this manner is given in Table 7-19, in absolute numbers and as a percentage of locomotive days available. If, under normal conditions, the railroads are operating at or near full capacity,* then the figures shown in the table represent the upper bound of lost freight-hauling capability.

TABLE 7-19
ANNUAL LOCOMOTIVE DAYS TAKEN UP BY RETROFIT PROGRAM

Compliance Period	Locomotive Days	Region			
		National	East	South	West
2-year	Absolute	17,048	9,252	2,143	6,378
	% of Total Available	.194%	.225%	.197%	.174%
5-year	Absolute	2,044	1,129	203	712
	% of Total Available	.023%	.027%	.0187%	.0195%

The impact of decreased hauling capability on the various commodities shipped by rail depends on how the railroads react to the capacity decrease. There are two ways in which demand for rail service can be made to equal the available supply: non-price rationing or price rationing. These will now be discussed.

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*See page 7-6 for a discussion of the probability of this occurring.

In the case of non-price rationing, the railroads could simply allow service to decline in quality while maintaining the same rates. The resulting delays and uncertainties in the transportation network would have differential impacts on the various commodities being shipped; those items highly sensitive to the quality of service will tend to be diverted to other modes of transportation. Commodities in this category are high-valued products, for which transportation charges are a small fraction of total value, and perishables.

Price rationing involves raising the price of service (with the approval of the ICC) in order to decrease demand to the level of the new, reduced capacity. Such a policy would affect commodities sensitive to freight rates; examples of these would be mineral ores and semifinished products. Such goods would tend to be shipped by other modes, or the quantity shipped would be reduced.

The probable magnitude of the effect of price rationing can be estimated. Table 7-19 shows that, in the worst case, capacity would decline by about .2% nationally. Assuming (from p. 7-22) that the elasticity of demand for rail transportation is about –.7 gives a price rise of .28% necessary to effect the required reduction in demand. This amounts to an average increase of .004 cents per ton mile relative to the 1971 average freight rate. This increase is fairly small, so minimal changes in transportation patterns may be expected as a result of the retrofit program.

SUMMARY AND CONCLUSIONS

Impact on the Railroad Industry

Cost. The cost of a muffler retrofit program is highly sensitive to the compliance period allowed. Maximum total cost for a 2-year program is estimated to be $103 million. Allowing 5 years for compliance would reduce the total cost to approximately $79 million.

Change in net revenues. The impact of a 2-year program would be to reduce overall Class I railroad annual net operating revenues by about 2%.

Effect on prices. For the railroads to recover the expense of a retrofit program would require an average freight rate increase of approximately .023 cents per ton mile in the 2-year case and .008 cents per ton mile in the 5-year case. These figures represent, respectively, 1.46% and .48% of the 1971 average freight rate.

Effect on capacity. A 2-year retrofit program would result in an annual loss of an many as 17,000 locomotive days, or about .2% of the total available, for the duration of the program. This would drop to about .02% for a 5-year program.

Impact on marginal railroads. Approximately a dozen railroads are in financial difficulties, as indicated by the computed values of a number of standard financial ratios. These roads may have difficulty in raising the funds necessary to pay for a retrofit program.

Impact on bankrupt railroads. Six roads are presently bankrupt, and may not be able to finance a retrofit program without an external source of funds. The total program cost for these roads would be $21 million for a 2-year program and $16 million for a 5-year program.

Impact on Users of Rail Services

Prices. Increases in freight rates would tend to encourage some shippers to seek alternate modes of transportation. This would occur primarily among shippers of commodities whose price is sensitive to transportation cost, such as semifinished products. It is not likely, however, that the small rate increases foreseen by this study would cause any major hardships or dislocations.

The current energy crisis may make any railroad rate increases insignificant compared with competitive modes of transportation, which would be more severely impacted by rising fuel costs.

Quality of service. A decrease in the haulage capacity of the railroads may result in the diversion of some freight to other modes of transport. Which commodities would be affected depends on how the railroad decided to reduce demand to the level of supply. If rates were raised, the effect would be the same as discussed in the previous paragraph. If rates remained constant but shipping delays were allowed to develop, commodities sensitive to transit time (such as perishables) would be most affected. Such diversions, however, will tend to be localized and on a small scale in view of the small reductions in capacity anticipated.

SECTION 8

ENVIRONMENTAL EFFECTS OF PROPOSED REGULATIONS

INTRODUCTION

The proposed regulations will immediately stop the noise emitted by railroad trains from increasing and over a 4-year period will progressively reduce the noise presently emitted by railroad locomotives. As a result, the number of people currently subjected to annoying levels of railroad noise will be reduced. It is essential to understand that these regulations are initial and that further noise reductions will be established in the future. Of equal importance is that these regulations are part of a comprehensive noise abatement effort aimed at reducing the total environmental noise to which the population is subjected. The composite impact of all Federal noise emission regulations will be aimed at a level of environmental noise consistent with human health and welfare.

IMPACT RELATED TO ACOUSTICAL ENVIRONMENT

Several studies have been conducted to estimate the reduction in noise levels, and the number of people who benefited as a result of the noise control standards proposed in this regulation.

Case Studies of Railroad Lines

Ten cities with widely varying populations were selected to make detailed comparisons of train traffic with population densities near railroad tracks and with the type of land use adjacent to tracks (see Table 8-1). Such comparisons provide a basis for determining how many people are exposed to railroad noise, how often they are exposed, and what activities they are engaged in at the time.

The schedules of trains moving over the railroad lines were determined from *The Official Guide of the Railways*, July 1973, or from employee timetables. Estimates of speed maxima and minima were taken from employee timetables or obtained from railroad employees. Speeds for AMTRACK trains were not obtained. The period between 10:00 p.m. and 7:00 a.m. was designated as "night," and the rest of each 24-hour period was designated as "day," Table 8-2 summarizes the results of the ten case studies.

Analysis of Train Noise Impact

There are three major noise sources that contribute to L_{DN} (see Enclosure A for definition of L_{DN}) at points along and away from railroad tracks: locomotives, wheel/rail interaction, and horns or whistles.

TABLE 8-1
LAND USE NEAR RAILROAD LINES

City and State	Land Use Within 500 Ft of Track (Percent)			
	Residential	Business	Industrial & Other	Mileage Studied
Newton, Mass.	75	21	4	6
Boston, Mass.	59	9	32	7
Valparaiso, Ind.	43	8	49	9
St. Joseph, Mo.	42	13	45	26
Akron, Ohio	40	23	37	25
Somerville, Mass.	30	18	51	7
Michigan City, Ind.	29	15	56	17
Kalamazoo, Mich.	22	5	73	20
Altoona, Pa.	16	18	65	6
Ft. Lauderdale, Fla.	12	22	66	21
Lewiston, Maine	12	19	68	11
Denver, Colo.	12	3	85	51
Cheyenne, Wyo.	9	11	79	15
Cambridge, Mass.	8	24	68	9
Macon, Ga.	6	4	90	25
Average	28	14	58	Total 255

TABLE 8-2
TRAIN TRAFFIC AND COMMUNITY CHARACTERISTICS NEAR TYPICAL RAILROAD LINES

CITY & STATE	POPULATION	NUMBER OF FREIGHT TRAINS		MAXIMUM FREIGHT SPEED (mph)	NUMBER OF PASSENGER TRAINS		MAXIMUM PASSENGER SPEED (mph)	LAND USE (%)			NO. OF PEOPLE PER SQUARE MI. WITHIN 500 FT	MILEAGE STUDIED	
		DAY	NIGHT		DAY	NIGHT		RESIDENTIAL	BUSINESS	OTHER		LAND USE	POPULATION
Akron, Ohio	542,775	22	18	55	0	0	---	40	23	37	1,662	[illegible]	31
Altoona, Pa.	81,795	7	5	50	2	2	70	16	19	65	3,090	6	12
Boston, Mass.	961,071	0	8	40	0	0	--	59	9	32	20,660	7	7
Cheyenne, Wyo.	40,914	?	?	?	?	0	?	9	11	79	1,471	15	9
Columbus, Ind.	27,141	1	1	50	0	0		?	?	?	730		20
Denver, Colo.	1,047,311	24	10	60	4	0	?	12	3	85	3,027	51	26
Durham, N.C.	100,764	11	1	65	0	0	--	?	?	?	1,780		31
Michigan City, Ind.	39,369	5	2	50	2	0	50	29	15	56	608	17	43
Newton, Mass.	91,066	7	1	50	0	0	-	75	21	4	5,320	6	6
Valparaiso, Ind.	20,020	19	10	60	0	0	---	43	8	49	1,528	9	9

Figure 8-1 shows some L_{DN} profiles that were calculated by applying the prediction techniques to actual operations on a specific railroad line. The profiles shown in Figure 8-1 were calculated from the following data supplied by Penn Central:

10:00 p.m. and 7:00 a.m.
6 freight trains
each 14 loaded cars and 10 empty cars
40 mph
and
7:00 a.m. and 10:00 p.m.
36 passenger trains, each
40 mph

Passenger trains with eight cars correspond to the national average passenger loading of cars (Moody, 1971). The curve for two cars is displayed in order to demonstrate the influence of the number of cars on the results.

Since there are no crossings along the branch picked for this study, no whistle noise was considered. In addition to the usual geometric attenuation, atmospheric absorption and ground surface attenuation (Beranek, 1971) were included in the calculation for Figure 8-1 (see Appendix B).

Figure 8-2 shows L_{DN} profiles that were calculated for the average of all the train movements in the U.S. The profiles were calculated from the following data (Moody, 1971);

Urban Areas

4 freight trains by day, 2 by night, each 33 mph, 40 cars 3800 tons

2 passenger trains by day, 0 by night, each 36 mph, 6 cars

Nonurban Areas

3 freights by day, 2 by night, each 33 mph, 40 cars, 3800 tons

0 passenger trains

Figures 8-3 through 8-6 provided examples of the impact on the community of a program to equip locomotive exhausts with mufflers. Figure 8-3 shows that a muffler that provides 10 dB(A) of quieting will nearly halve the distance to which people are exposed to L_{DN} of 55 or more by train traffic on the Dorchester Branch of Penn Central (assuming that no other sources of locomotive noise produce levels comparable to exhaust noise levels). Figure 8-4 shows that there is a reduction of 24,000 people exposed to L_{DN} of 55 or more by train traffic on the 7.2-mile-long Dorchester Branch. Figure 8-5 is based on national average train traffic and also shows that a muffler that quiets locomotive exhaust noise by 10 dB(A) will more than halve the distance to which people are

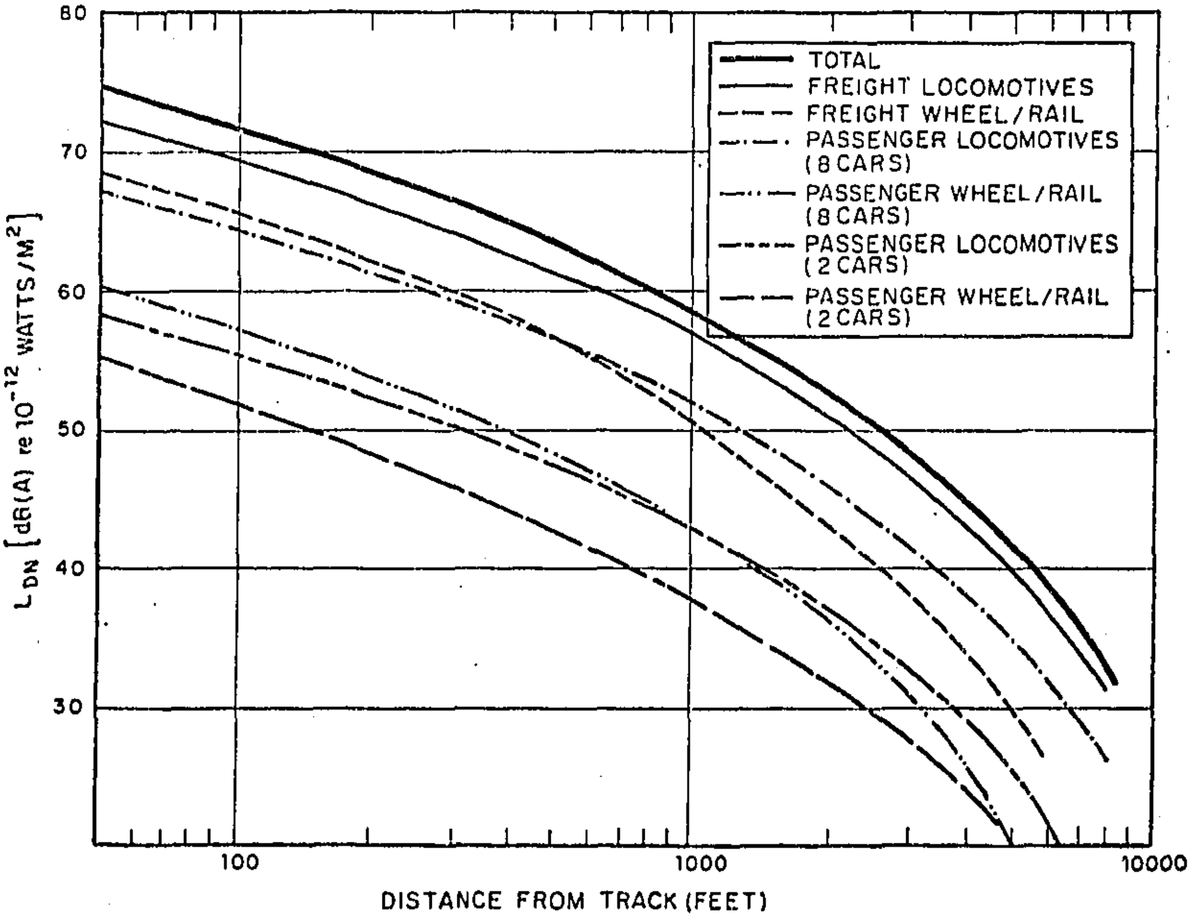

Figure 8-1. L_{DN} vs Distance From the Track for the Dorchester Branch of Penn Central

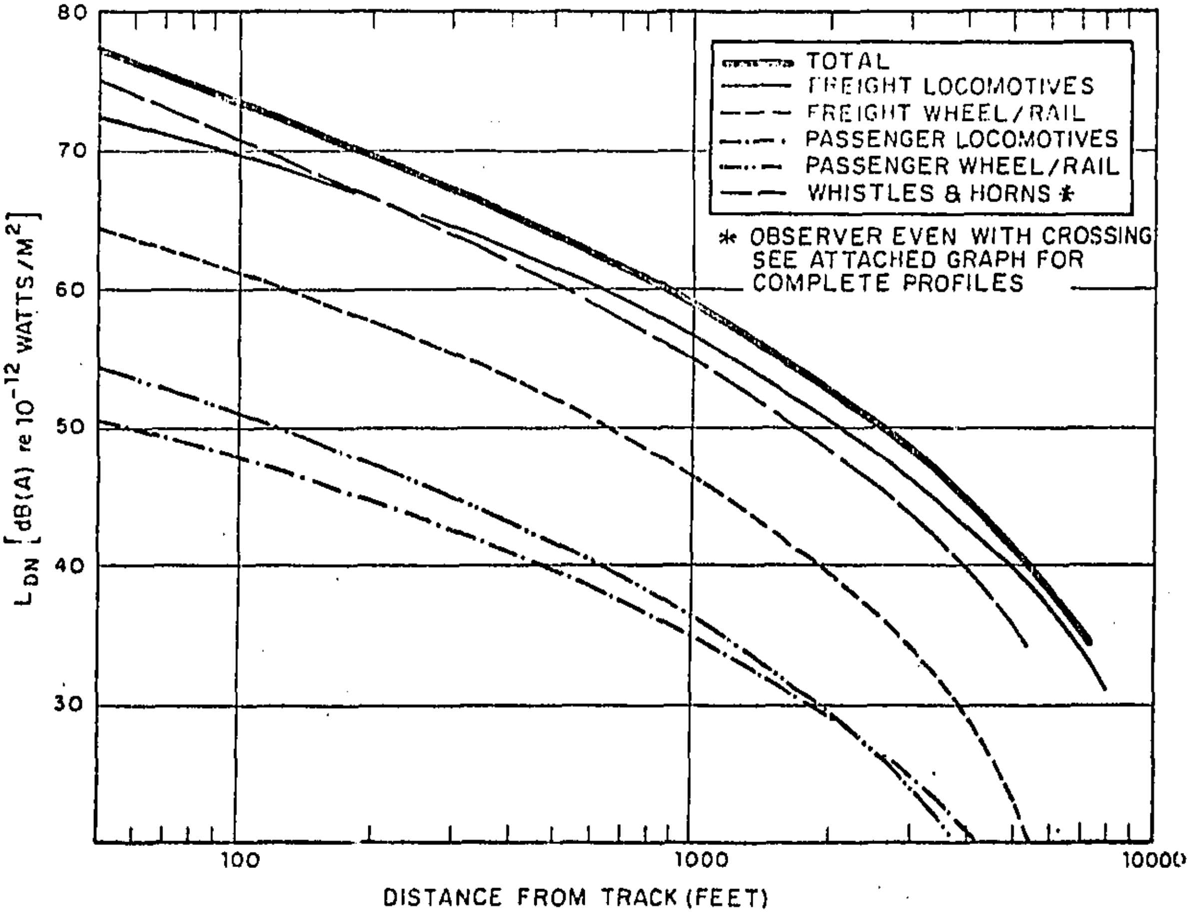

Figure 8-2. L_{DN} vs Distance From Track for National Average Train Traffic

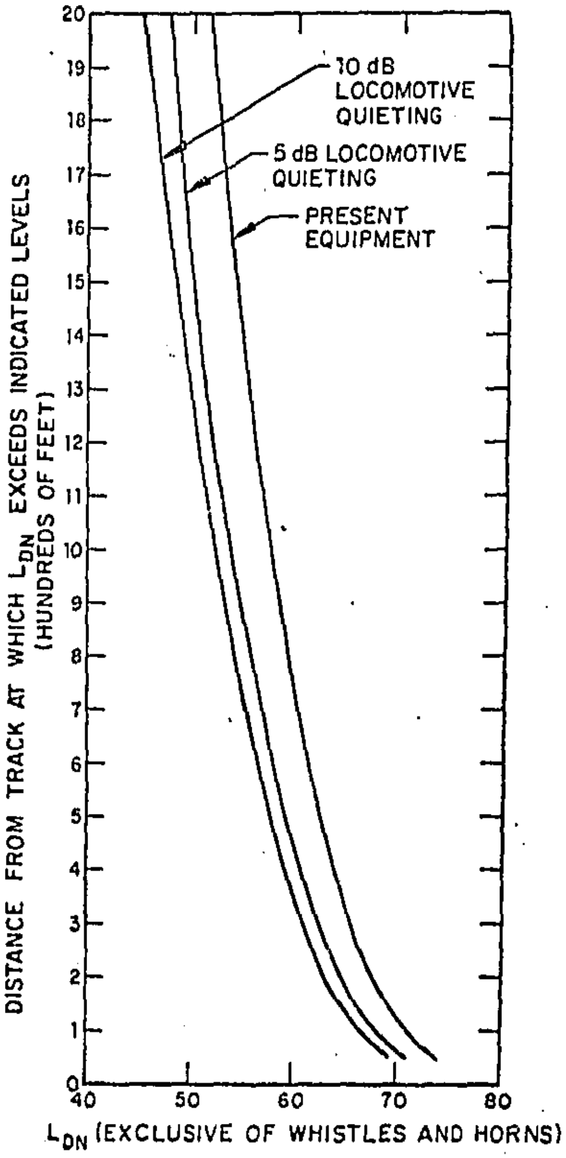

Figure 8-3. Distance From Track at Which Various L_{DN} Occur Around the Dorchester Branch of the Penn Central

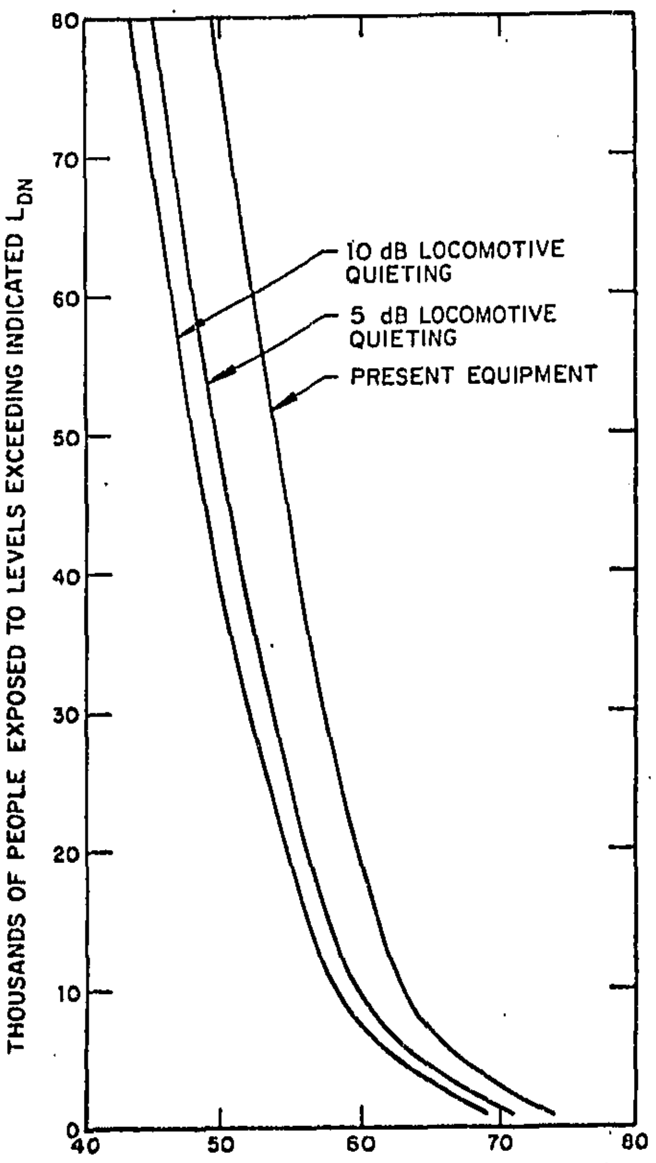

Figure 8-4. Thousands of People Exposed to Various L_{DN} by 7.2 Miles of Track on the Dorchester Branch of the Penn Central

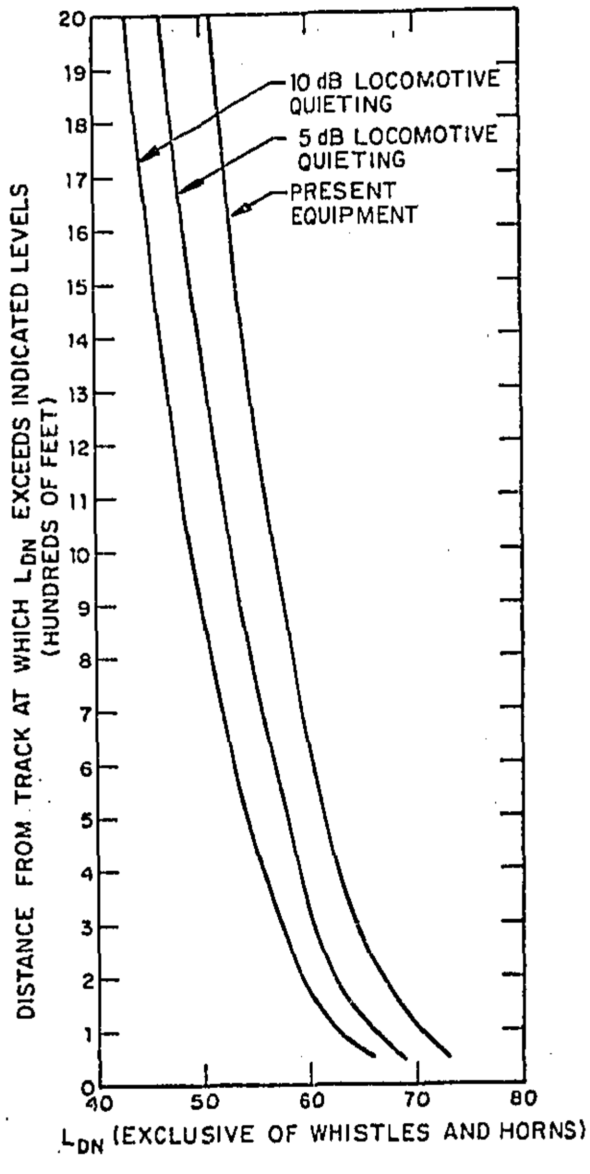

Figure 8-5. Distance From Track at Which Various L_{DN} Occur Due to National Average Train Traffic

exposed to L_{DN} of 55 or more (assuming that no other sources of locomotive noise produce levels comparable to exhaust noise levels). Figure 8-6 shows that there is a corresponding 5.1 million reduction in the number of people exposed to L_{DN} of 55 or more based on national average train traffic.

Population densities used to construct Figures 8-3 and 8-6 were obtained from the U.S. Department of Commerce, Bureau of the Census. The census results show 28,098 people living within 1000 feet of the 7.2 miles of track comprising the Dorchester Branch of Penn Central. The population density in the first 500 feet next to the line was taken to be one-half of the density for the entire region, in keeping with national trends.

The figures for the number of people exposed to noise from national average train traffic were based on estimates of 30,000 miles of railroad rights-of-way in urban areas in the U.S. Urban areas are defined as the 40 Standard Metropolitan Statistical Areas (SMSAs) having average population densitites in excess of 500 people per square mile and a total population greater than 250,000. The 40 SMSAs defined above have a total land area of 58,200 square miles and a total population of 71,082,000, for an average population density of 1220 people per square mile. This figure must be modified, however, as there tends to be a concentration of industrial, commercial, and other nonresidential activities in the vicinity of rail lines. Land use and zoning maps indicate that the residential population density in the vicinity of a railroad line tends to be about 50% of the average density for the entire region.

IMPACT RELATED TO LAND

These regulations will have no adverse effects relative to land.

IMPACT RELATED TO WATER

These regulations will have no effect on water quality or supply.

IMPACT RELATED TO AIR

The use of more efficient exhaust muffling systems can cause a change in the back pressure to the engine and may result in a change in the exhaust emissions level. Little work has been performed regarding this problem. The data, at present, are insufficient to make other than a general statement concerning the directions the various emission levels take when a different back pressure is applied, since the behavior of the various engines and exhaust emission control systems vary widely. However, internal combustion engine exhaust emissions are affected by changes in exhaust system back pressure, as evidenced by the tests of gasoline engines at the University of Michigan (Bolt, Bergin, Verper, 1973), and they must be considered. It is important to note, however, that motor carrier exhaust emissions are approximately 3.7 times higher than rail carrier exhaust emissions per ton mile of goods transported (Battelle Laboratories, 1971), indicating that rail carriers could be allowed some latitude regarding exhaust emissions, in order to help solve the noise problems.

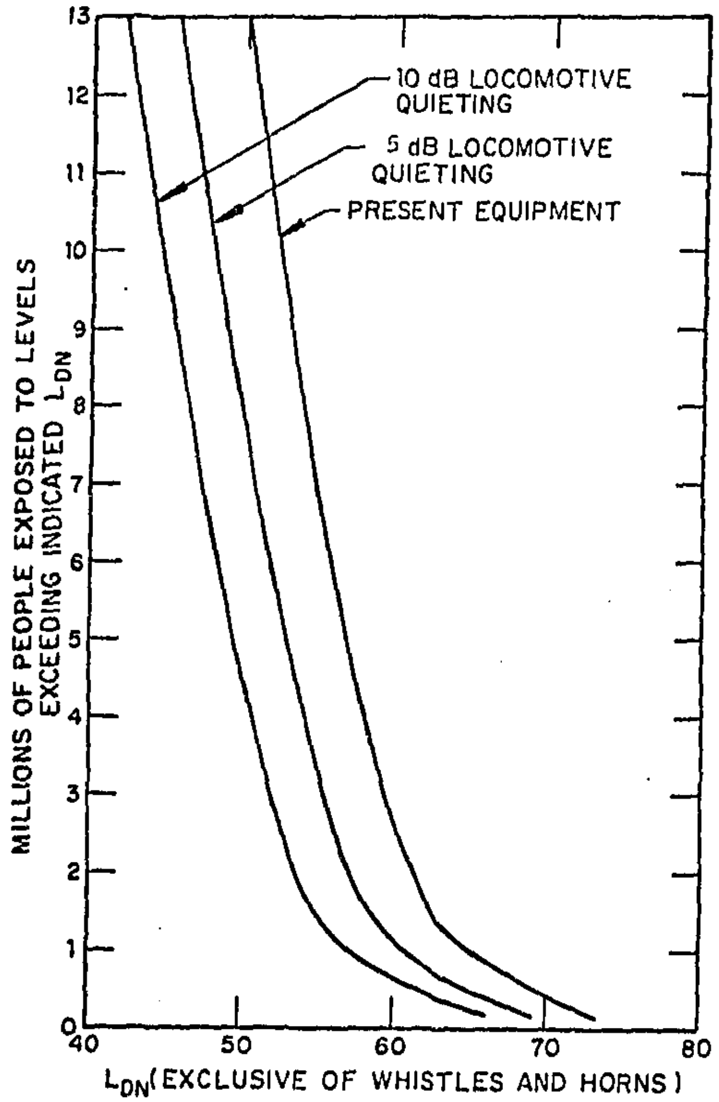

Figure 8-6. Millions of People Exposed to Various L_{DN} by National Average Train Traffic

It must also be noted that promulgating stricter rail carrier noise regulations at this time may inadvertently divert cargo traffic from the rails toward motor carriers due to difficulties in compliance with regulations, thereby causing an increase in total exhaust emissions to the atmosphere, as well as increasing noise emissions. Based on the analysis presented, problems such as this are not expected to arise as a result of the proposed regulations.

ENCLOSURE A: "DAY NIGHT EQUIVALENT NOISE LEVEL" (L_{DN})

L_{DN} is a modified energy-equivalent sound level. The energy-equivalent sound level L_{EQ} is the level of the continuous sound associated with an amount of energy equal to the sum of the energies of a collection of discontinuous sounds. L_{EQ} is defined by

$$L_{EQ} = 10 \log \frac{1}{t_2 - t_1} \int_{t_1}^{t^2} 10^{NL/10} \, dt \qquad (9\text{-}1)$$

where NL is the instantaneous overall noise level in dB(A) at time t, and the time period of interest is from time t_1 to time t_2. L_{DN} is determined precisely like L_{EQ}, except that all noise levels NL measured at night (between 10:00 p.m. and 7:00 a.m.) are increased by 10 dB(A) before being entered into the above equation.

ENCLOSURE B: EXCESS ATTENUATION OF RAILROAD NOISE

Many mechanisms cause attentuation of sound beyond that caused by geometric spreading, including molecular absorption in the air, precipitation, barriers, ground cover, wind, and temperature and humidity gradients. The attenuation varies with location, time of day, and season of the year. To account for the attenuation produced by these highly variable sources, it is necessary to compile detailed records of wind, temperature, humidity, precipitation, and even cloud cover on a statistical or probabilistic basis. The following discussion is directed at a base case that includes two sources of excess attenuation that can be relied upon: atmospheric molecular absorption and attenuation associated with variations in the physical characteristics of the atmosphere near the ground. Both attenuations vary with frequency. The attenuation factors were evaluated for reference conditions of 50°F and 50% relative humidity.

Figure 8-1 shows how atmospheric molecular absorption and variations of atmospheric characteristics near the ground change the shape of the locomotive noise spectrum. Notice that the high frequencies become less important as the sound travels outward from the source. The attenuation of the overall sound level (logarithmically summed octave-band sound levels) was found to be about 2dB per thousand ft out to 4000 ft. That value was used to calculate the propagation of locomotive noise described in this report. The value for the effective overall attenuation coefficient for locomotive noise is about the same for throttle position 8 and throttle position 1.

Figure 8-2 shows how the frequency-dependent attenuations change the shape of the spectrum of wheel/ rail noise. Notice that here, too, the high frequencies become less important as the sound

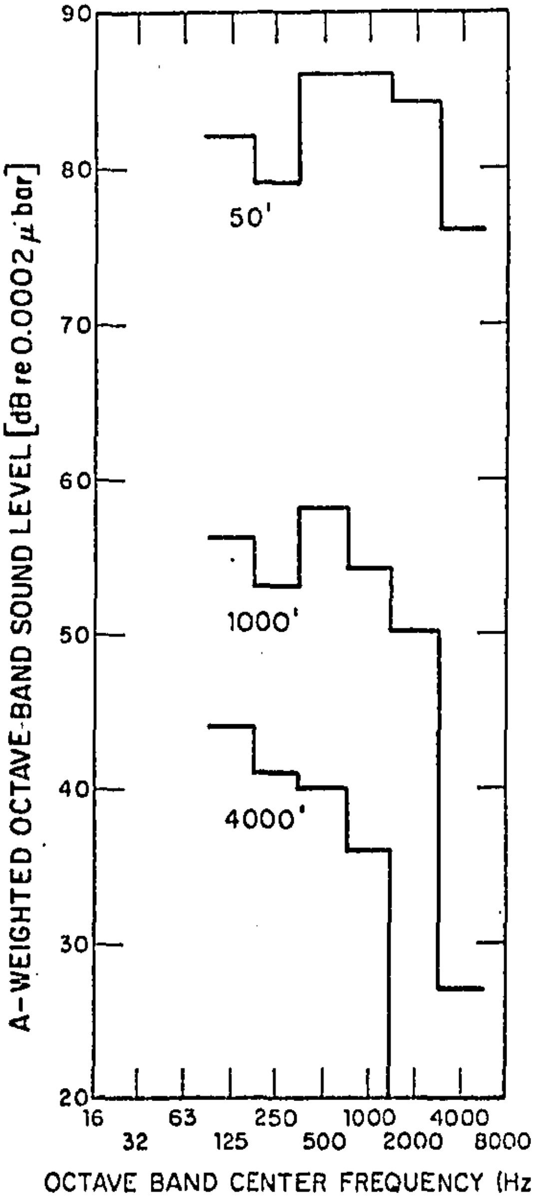

Figure 8-7. Influence of Frequency-Dependent Attenuations on Locomotive Noise Spectrum (See Figure A.1.7b for Comparison)

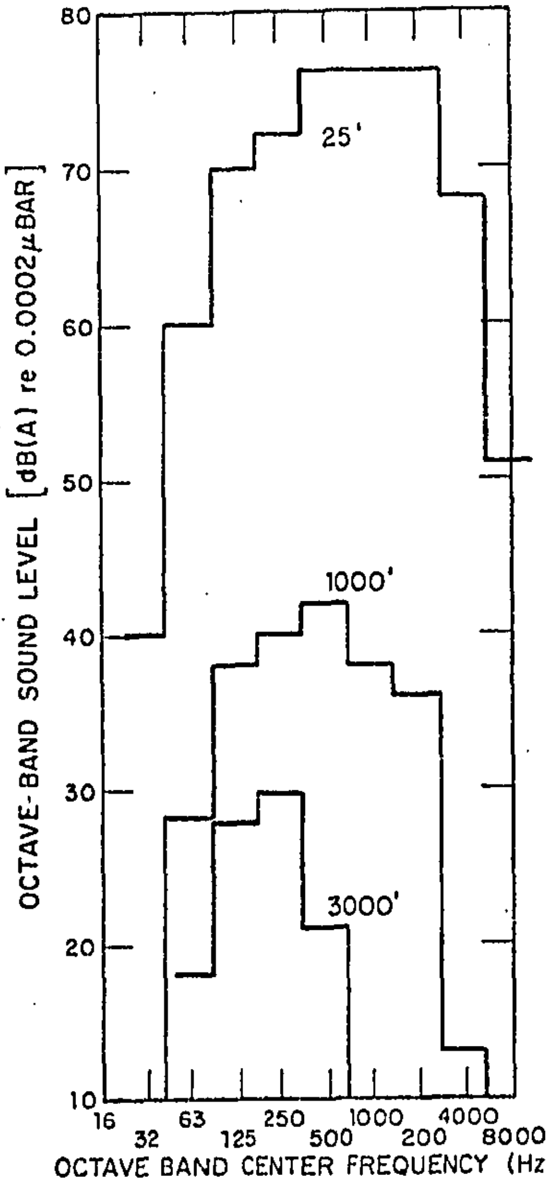

Figure 8-2. Influence of Frequency-Dependent Attenuations on Wheel/Rail Noise, Train No. 6, Region 2 (See Figure B.1.13 for Comparison)

travels outward from the source. The attenuation of the overall sound level (logarithmically summed octave-band sound levels) was about 3 dB per thousand ft out to 3000 ft. That value was used to calculate the propagation of locomotive noise described in this report.

SECTION 9

SELECTION OF THE PROPOSED REGULATIONS

PROBLEM ADDRESSED AND APPROACH

Problem Addressed

The problem addressed in the proposed noise emission regulations is the development of noise emission regulations that will control railroad noise and Federally preempt conflicting State and local noise emission regulations, taking into consideration that (1) State and local governments have the primary responsibility to protect the environment from noise and (2) Federal preemption may be waived in the case of use or operational regulations if special local conditions exist and if the State and local regulation in question is not in conflict with the noise emission regulations established under Section 17.

Approach

In order to develop these noise emission regulations, the following approach, based on the statutory requirements of the Noise Control Act of 1972, was utilized:

1. Determination of the sources of railroad noise to be Federally regulated
2. Determination of the best available technology to achieve noise reduction
3. Determination of the cost of compliance to the railroad industry with possible noise emission regulations
4. Determination of the environmental and economic impact of possible noise emission regulations
5. Selection of the appropriate noise emission standards

REGULATORY APPROACHES CONSIDERED

"Status Quo" Regulations Alternative

Status quo regulations for both locomotives and railroad car noise could be proposed that would preempt State and local regulations. These status quo regulations would not reduce noise but rather limit it to present levels and would have no financial impact on the railroads beyond standard maintenance already required. The function of status quo regulations is, therefore, one in which the intent of the Federal government to revise the status quo regulations is an implicit statement that such future revision will result in reduction in noise levels with probable concurrent financial impact on the railroad industry. Thus, a status quo regulation placed on certain equipment and facilities would establish the direction and intent of Federal regulation on those sources in the future. The rationale for the issuance of status quo regulations would be that the financial impact of more stringent regulations at this time would be unreasonably high relative to the noise reduction achieved. Also, if noise abatement technology were not available, status quo regulations could be established to place a ceiling on noise emissions and allow time for further technology development.

Future Noise Standards Regulations Alternative

The data gathered by EPA indicate that it is feasible to reduce railroad noise with presently available technology at a reasonable cost. However, the shortest feasible time to apply this technology on a retrofit basis at a reasonable cost is 4 years. Thus, a regulation requiring the application of this technology could be promulgated with an effective date 4 years in the future.

Section 17 provides for Federal preemption of State and local regulations upon the effective date of the Federal standards. Therefore, during the 4-year period required for the application of technology, State and local regulations could be established and enforced.

Noise Reduction in Combination with Status Quo Regulations Alternative

As pointed out in the previous alternative, if a regulation were promulgated with an effective date some time in the future, State and local regulations would not be preempted until this date. However, it is not feasible for a noise reduction regulation on trains to be effective in less than 4 years when based on available technology and cost. It, therefore, would appear unreasonable to expect quieting of trains during this period. However, it is not unreasonable to expect that equipment be maintained properly to eliminate unnecessary noise. To accomplish this goal, a status quo regulation based on proper maintenance practice could be made effective earlier. This would not have substantial economic impact, nor would it produce significant noise reduction. It would, however, ensure that noise will not increase during the period prior to the installation of noise abatement equipment. Further, it would preclude the State and local governments from establisning what might be unreasonable standards during this interim period.

REGULATORY APPROACH SELECTED BY EPA

The Environmental Protection Agency has chosen to adopt the last alternative discussed. It is believed that this approach is the most environmentally sound alternative and one that fulfills all the requirements of Section 17.

DISCUSSION OF PROPOSED REGULATIONS

The proposed noise emission regulations will establish standards for levels of noise emissions from all locomotives (except steam powered)and railroad cars. The standards are based on measurements of noise emission at a distance of one hundred feet from the centerline of the railroad track. Measurements will be made in decibels on the A-weighted scale, utilizing the fast meter response, based on the measurement methodology prescribed in the regulation.

All locomotives (except steam powered) operated by surface carriers engaged in interstate commerce by railroad are to meet the following noise emission standards: effective 270 days after promulgation of these regulations, 93 dB(A) at any throttle setting and 73 dB(A) at idle; effective 4 years after promulgation of these regulations, 87 dB(A) at any throttle setting and 67 dB(A) at idle.

Effective 270 days after promulgation of these regulations, all railroad cars operated by surface carriers engaged in interstate commerce by railroad are to meet a noise emission standard of 88 dB(A) at speeds up to 70 mph and 90 dB(A) at speeds greater than 70 mph.

Based upon the strict language of the Noise Control Act of 1972, its legislative history, and other relevant data, "best available technology" and "cost of compliance" have been defined as follows:

"Best available technology" is the noise abatement technology available for application to equipment and facilities of surface carriers engaged in interstate commerce by railroad that produces meaningful reduction in the noise produced by such equipment and facilities. "Available" is further defined to include:

1. Technology that is currently known to be feasible.
2. Technology for which there will be a production capacity to produce the estimated number of parts required in reasonable time to allow for distribution and installation prior to the effective date of the regulation.
3. Technology that is compatible with all safety regulations and which takes into account operational consideration, including maintenance and other pollution control equipment.

"Cost of compliance" is the cost of identifying what action must be taken to meet the specified noise emission level, the cost of taking that action, and any additional cost of operation and maintenance caused by that action.

Currently existing technology known to reduce locomotive noise consists of (a) fan modification, (b) engine casing modification, and (c) muffler retrofit. Applications of fan modification and engine casing modification were not included in establishing the noise emission levels in the proposed regulations because of lack of equipment availability, prohibitive and limited cost data, and low relative effectiveness in noise reduction. Muffler retrofit to the locomotive engine exhaust system was determined to be the only method that meets the criteria established above for "best available technology."

Currently existing technology known to reduce railroad car noise consists of (a) replacement of the bolted rail with the welded rail, (b) structural maintenance to railroad car bodies, and (c) elimination of flat spots on wheels. The proposed noise emission regulations did not include replacement of the bolted rail with the welded rail and structural maintenance to railroad car bodies because of prohibitive cost and lack of data. Elimination of flat spots on wheels can be achieved through effective maintenance, without added cost for compliance.

Conclusion The only standards that can be adequately based on "best available technology" and "cost of compliance" at this time are (1) the muffler retrofit to control locomotive exhaust and (2) effective railroad car maintenance. The proposed regulations, therefore, require locomotives to eventually meet a noise emission standard that results in significant reduction in noise through the installation of exhaust mufflers. The proposed railroad car noise emission standard is designed to ensure that railroad cars will be properly maintained so that train noise levels will be as low as the available technology permits.

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Wyle Laboratories (1973), Preliminary Data from Wyle Laboratories Research Project No. 59141, "Communities Noise Profiles for Typical Railroad Operations."

Railroad Contacts

Personnel in the operations departments of the following railroads were contacted in the course of this study.

AMTRAK
Atchison, Topeka, and Santa Fe
Baltimore and Ohio
Boston and Maine
Burlington Northern
Chesapeake and Ohio
Chicago, Milwaukee, St. Paul, and Pacific
Chicago and North Western
Chicago, Rock Island, and Pacific
Denver and Rio Grande Western
Durham and Southern
Gulf, Mobile, and Ohio
Illinoise Central Gulf
Louisville & Nashville
Norfolk Southern
Norfolk and Western
Penn Central
Union Pacific

Yard superintendents, yard masters, or engineering department personnel with the following railroad companies were contacted in the course of this study.

Chicago, Milwaukee, St. Paul, and Pacific Railroad Yards,
Bensenville, Illinoise

Chesapeake & Ohio/Baltimore & Ohio Railroad Yard,
Walbridge, Ohio

Illinois, Central and Gulf Railroad Yard
Markham, Illinois and Centreville, Illinois

Norfolk & Western Railroad Yard,
Bluefield, West Virginia

Penn Central Railroad Yard,
Elkhart, Indiana

Boston and Maine Railroad Yard,
Mechanicville, New York

Southern Pacific Railroad Yard,
Roseville, California

Union Pacific Railroad Yard,
Cheyenne, Wyoming

Burlington Northern Railroad
Chicago, Illinois and St. Paul, Minnesota

BACKGROUND DOCUMENT AND ENVIRONMENTAL EXPLANATION

for the

PROPOSED INTERSTATE RAIL CARRIER NOISE CONTROL REGULATION

APPENDICES A-G

TABLE OF CONTENTS

APPENDIX A: MEASUREMENT OF NOISE FROM DIESEL LOCOMOTIVES CONNECTED TO LOAD CELLS

A.1 Mississippi Street Diesel Shop, St. Paul, Minnesota

On April 25, 1973, BBN personnel measured noise around a stationary 3-month-old General Motors, SW-1500 1500-hp locomotive connected to load cells* at Burlington Northern's Mississippi Street Diesel Shop, in St. Paul, Minnesota. Measurements of noise due to the locomotive operation were made at various distances from the locomotive (Fig. A.1) and near individual locomotive components (Fig. A.1.3). Measurements were obtained for the lowest and the highest throttle settings.

The following instruments were used in the tests.

2 Bruel & Kjaer Model 431 1-in. condenser microphones
2 Bruel & Kjaer Model 2203 sound level meters
2 Bruel & Kjaer Model 4220 pistonphone calibrators
2 Nagra Model Kudelski III tape recorders.

The microphones were mounted on the sound level meters, with both the microphones and the meters oriented vertically and mounted on tripods 4 ft above the ground, as shown in the photographs in Figs. A.1.4 and A.1.5. The sound level meters were calibrated before and after the tests. The measurements were made during the morning of April 25, 1973. The temperature was 55°F, the relative humidity was 30%, and the sky was clear. A wind was blowing at 5 - 7 mph, with gusts to 10 mph, from the northeast (from the observer toward the locomotive).

Figures A.1.6 and A.1.7 show the measured spatial distribution of sound level for the locomotive operating at throttle settings 1 and 8. Figure A.1.8 shows A-weighted 1/3-octave band spectra of

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* Electrical resistors to dissipate the power developed by the locomotive.

the sound recorded at measurement position 5 while the locomotive was operating at throttle settings 1 and 8.

A.2 Burnham Shops, Denver, Colorado

On May 2, 1973, BBN personnel measured noise around a stationary 1-year-old General Motors EMD GP40-2 3000-hp locomotive connected to load cells* at Denver and Rio Grande Western's Burnham Shops, in Denver, Colorado. Measurements of noise due to the locomotive's operation were made at various distances from the locomotive (Fig. A.2.1) and near individual locomotive components (Fig. A.2.3). Measurements were obtained for the lowest and highest throttle settings.

The instrumentation and test procedure are described in Sec. A.1. The photographs in Fig. A.2.2 and A.2.4 show the configuration of the equipment. The measurements were made during the morning. The temperature ranged from 45° – 52°F; the relative humidity ranged from 32 – 34%. There was a 1 to 4 mph wind blowing from the northeast (away from the observer, toward the locomotive).

Figures A.2.5 and A.2.6 show the measured spatial distribution of sound level for the locomotive operating at throttle settings 1 and 8. Figure A.2.7 shows A-weighted 1/3-octave band spectra of the sound recorded at measurement position 5. Figure A.2.8 shows A-weighted narrow band spectra of the sound recorded 3 ft from the center of the exhaust and about 3 ft from the termination of the exhaust for two throttle settings. The solid triangles indicate the harmonics of the crankshaft rotation rate. Only the major peaks have been labeled. Apparently, each cylinder contributes independently to the exhaust noise. Only one readily distinguishable peak is not associated with a harmonic of the crankshaft rotation rate. The peak near 55 Hz in the spectrum for throttle 8 may be associated with the operation of an auxiliary component of the locomotive.

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* see note on previous page

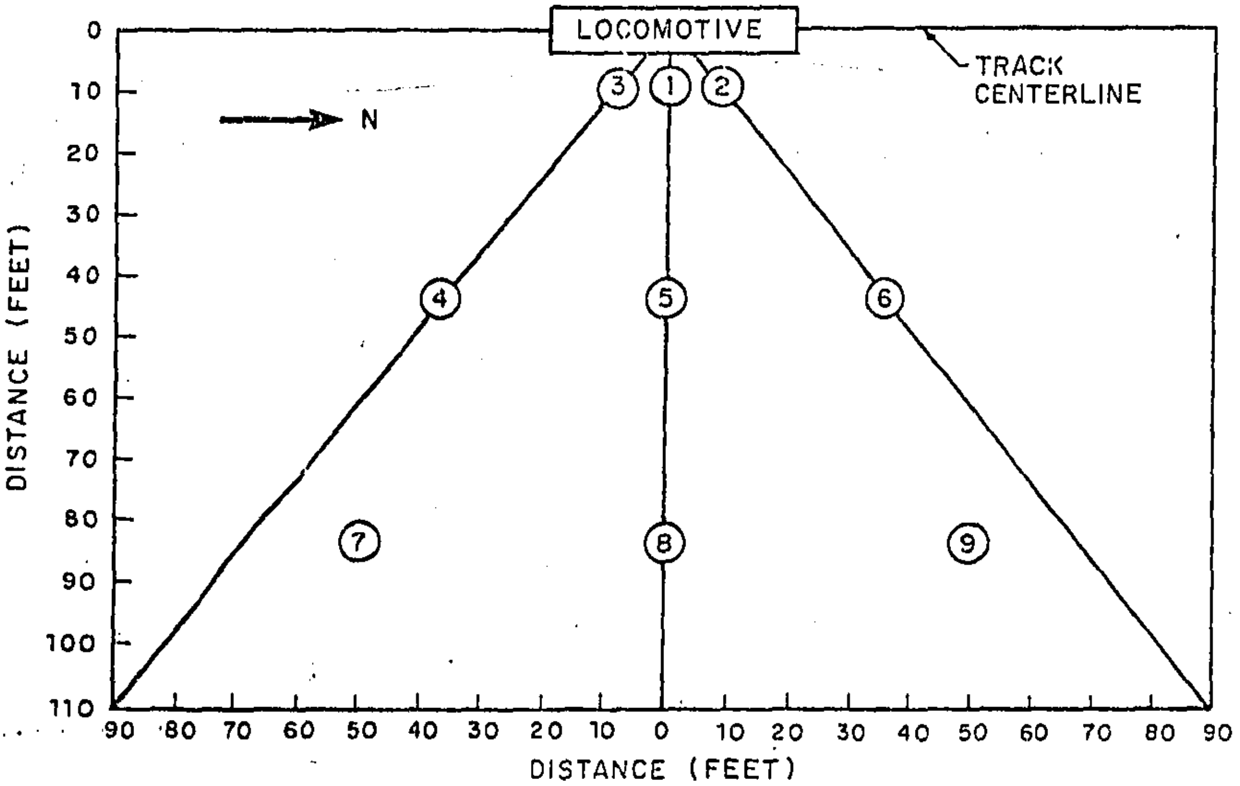
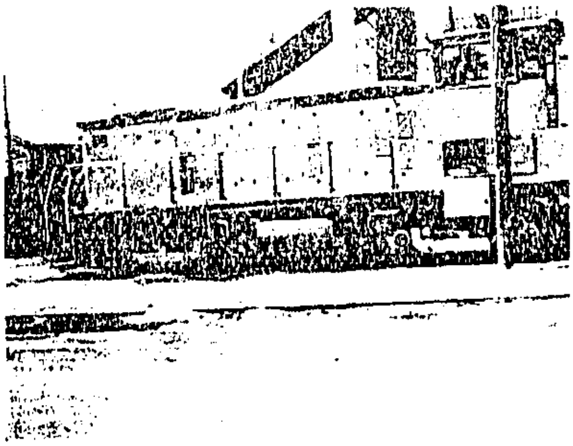
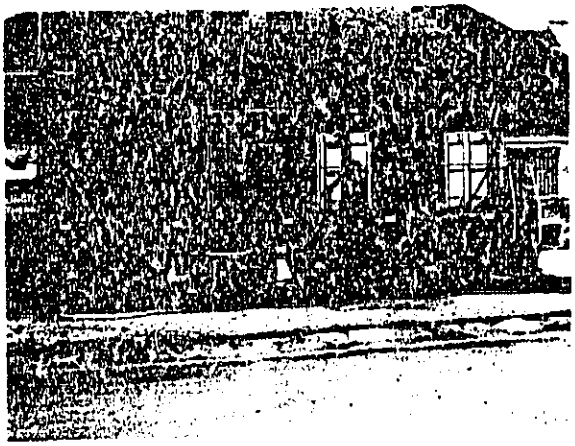


FIG. A.1.1. LOCATION OF THE MEASUREMENT POINTS AROUND A STATIONARY GM SW-1500 LOCOMOTIVE AT BURLINGTON NORTHERN'S MISSISSIPPI STREET DIESEL SHOP, ST. PAUL, MINNESOTA



(a) GM 4624-5 Class 0440 Locomotive Showing Side that was to be Connected to Grid



(b) Locomotive Connected to Grid — Access Doors Open (Grid is Behind Locomotive)

FIG. A.1.2. PHOTOGRAPHS OF A GM SW-1500 LOCOMOTIVE ON A LOAD CELL

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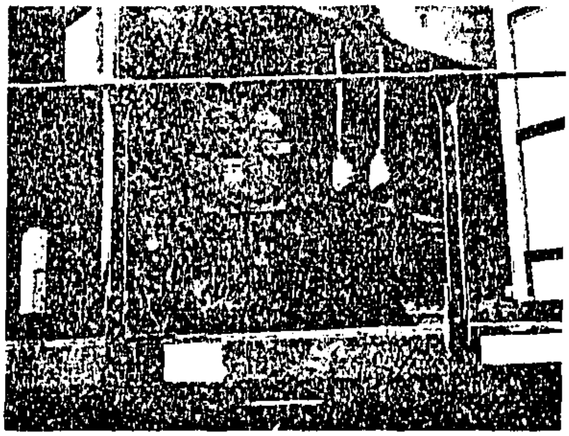
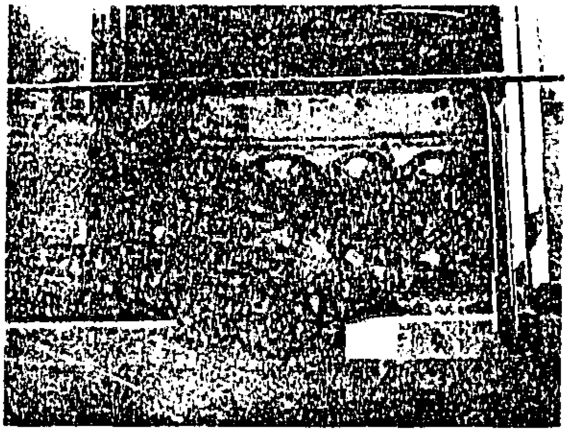


(a) Forward Compartment — Compressor, Fan, and Water Pump



(b) Middle Compartment — Diesel Engine

FIG. A.1.3. PHOTOGRAPHS OF COMPONENTS OF A GM SW-1500 LOCOMOTIVE ON A LOAD CELL

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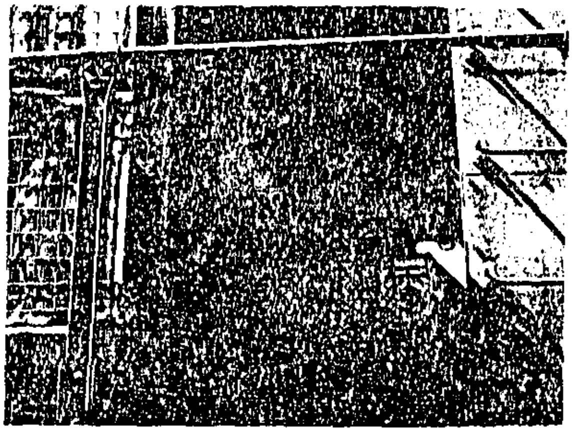

(c) Aft Compartment – Main Generator

FIG. A.1.3. (CONT.)

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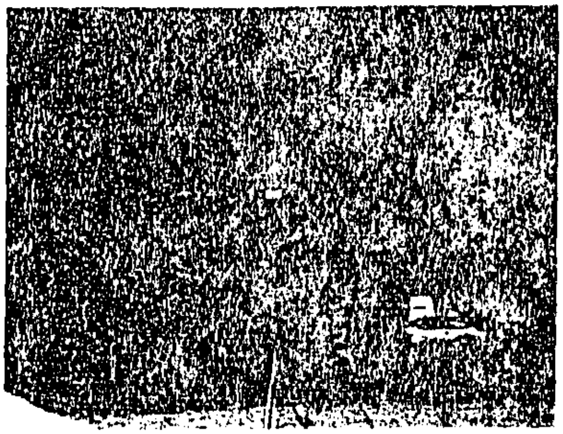
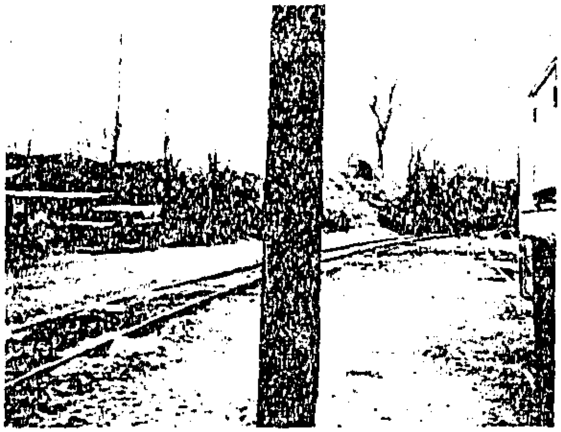
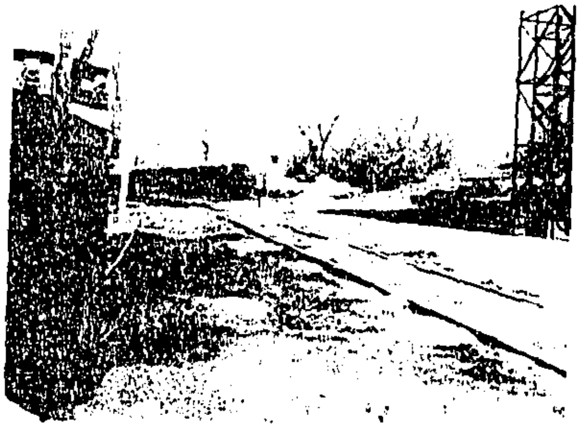


(a) Looking from Position 1, Toward the Locomotive



(b) Looking Aft (South) of the Locomotive from Position 1

FIG. A.1.4. PHOTOGRAPHS OF MEASUREMENT POINT NO. 1, 10 FT FROM TRACK CENTER



(c) Looking Forward (North) of the Locomotive from Position 1

FIG. A.1.4. (CONT.)

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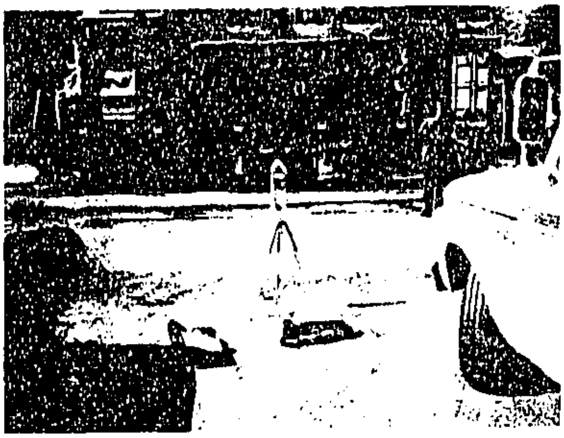

(a) Looking West Toward the Locomotive, Past Position 5

(b) Looking East from the Locomotive, Toward Position 5

FIG. A.1.5. PHOTOTRAPHS OF MEASUREMENT POSITION 5, 45 FT FROM TRACK CENTER

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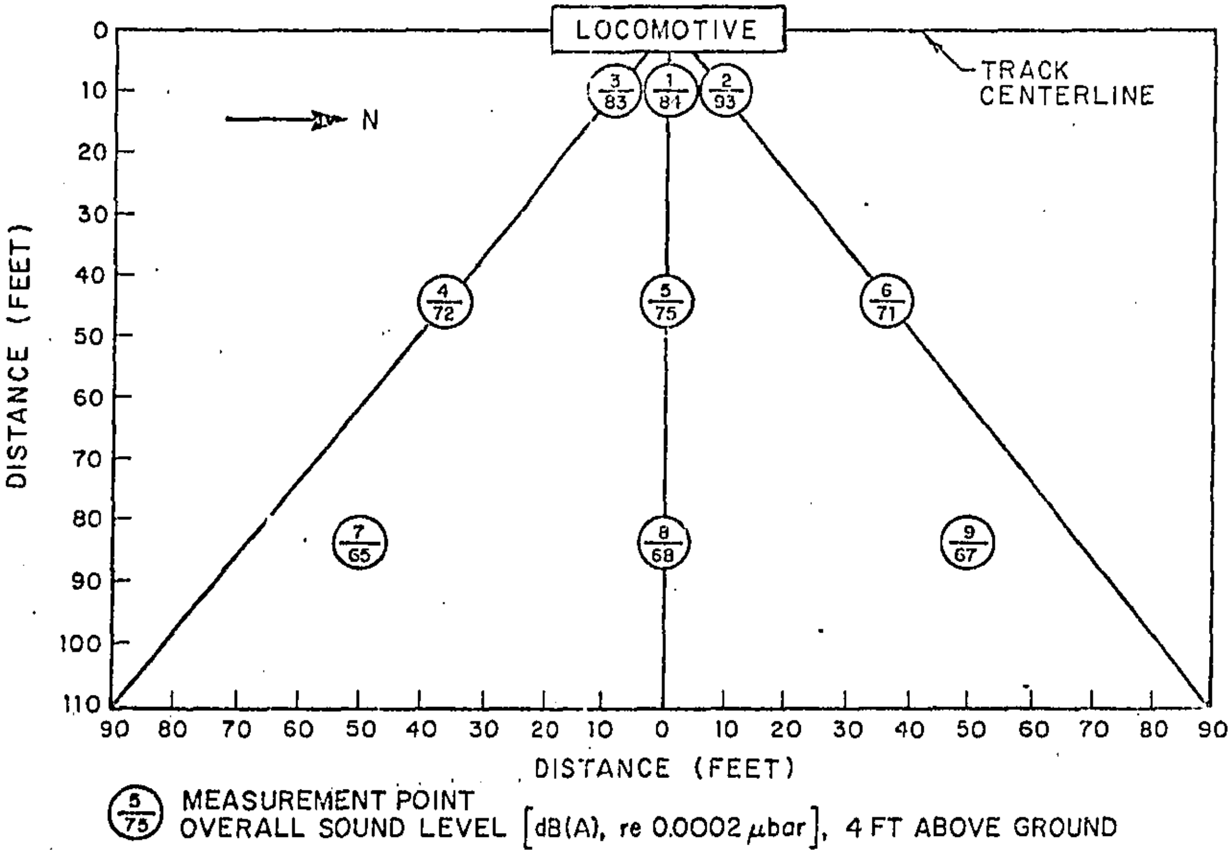

FIG. A.1.6. SOUND DISTRIBUTION AROUND STATIONARY GM SW-1500 (1500 hp) LOCOMOTIVE (3 MONTHS OLD), AT THROTTLE SETTING 1, MEASURED AT THE BURLINGTON NORTHERN MISSISSIPPI STREET DIESEL SHOP, ST. PAUL, MINN.

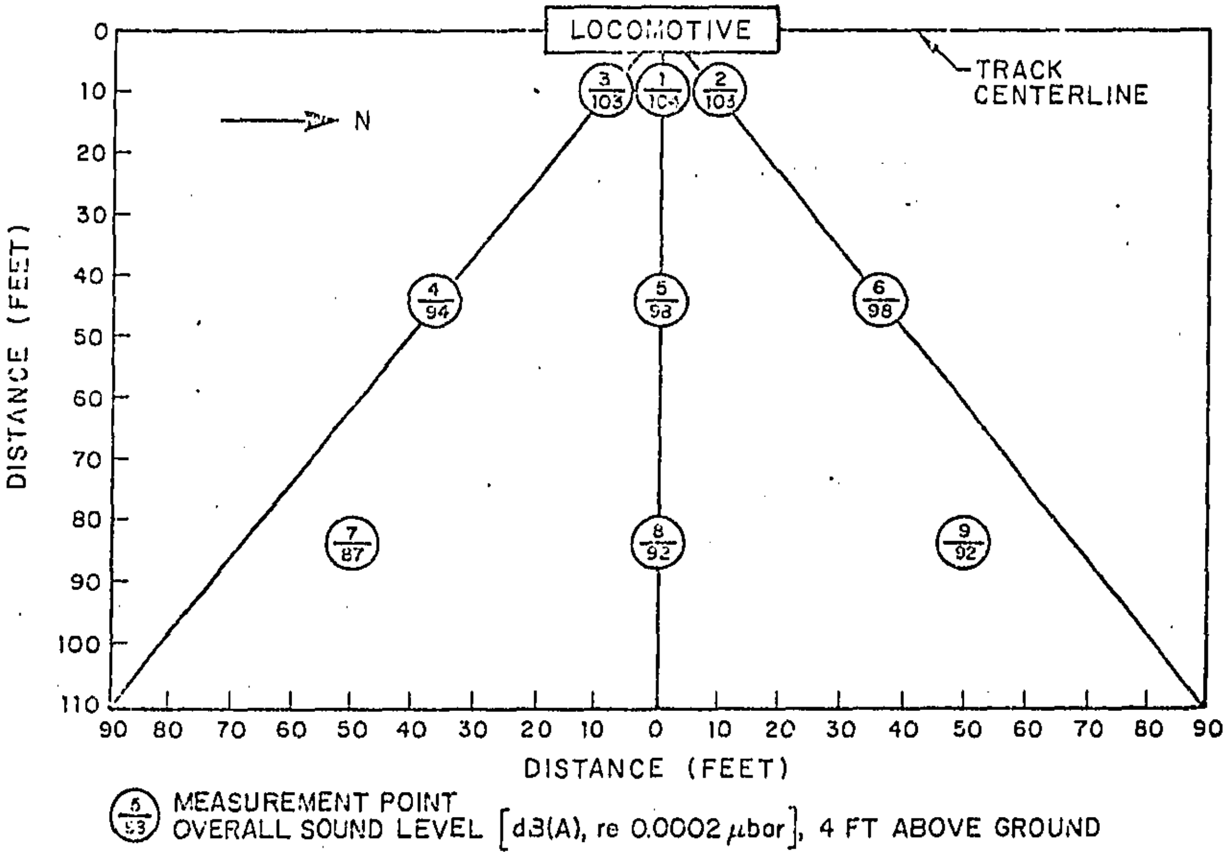

FIG. A.1.7. SOUND DISTRIBUTION AROUND A STATIONARY GM1500 (1500 hp) LOCOMOTIVE (3 MONTHS OLD), AT THROTTLE SETTING 8, MEASURED AT THE BURLINGTON NORTHERN MISSISSIPPI STREET DIESEL SHOP, ST. PAUL, MINNESOTA

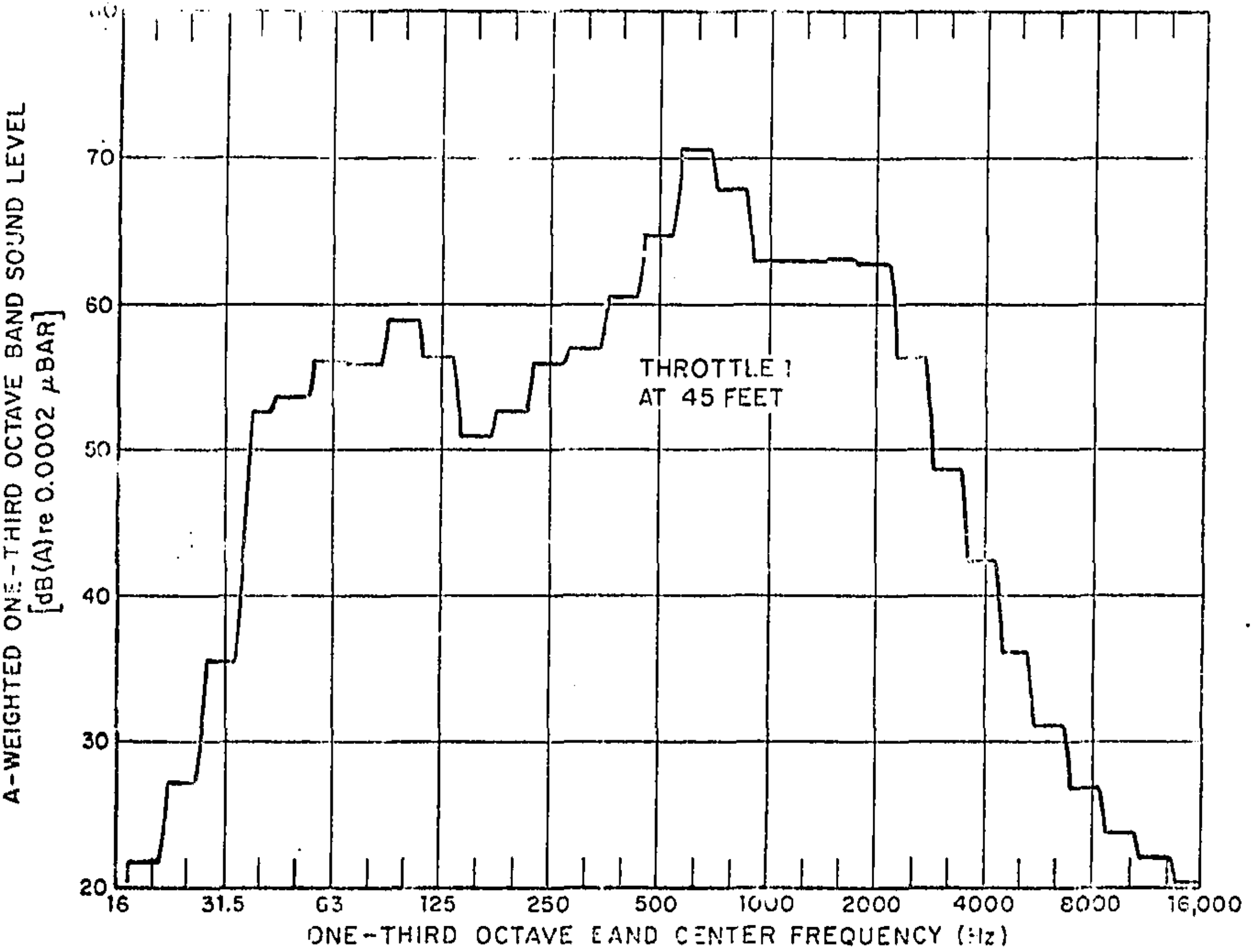

FIG. A.1.8(a) FREQUENCY ANALYSIS OF NOISE 45 FT TO THE SIDE OF A GM SW-1500 LOCOMOTIVE AT THROTTLE SETTING 1

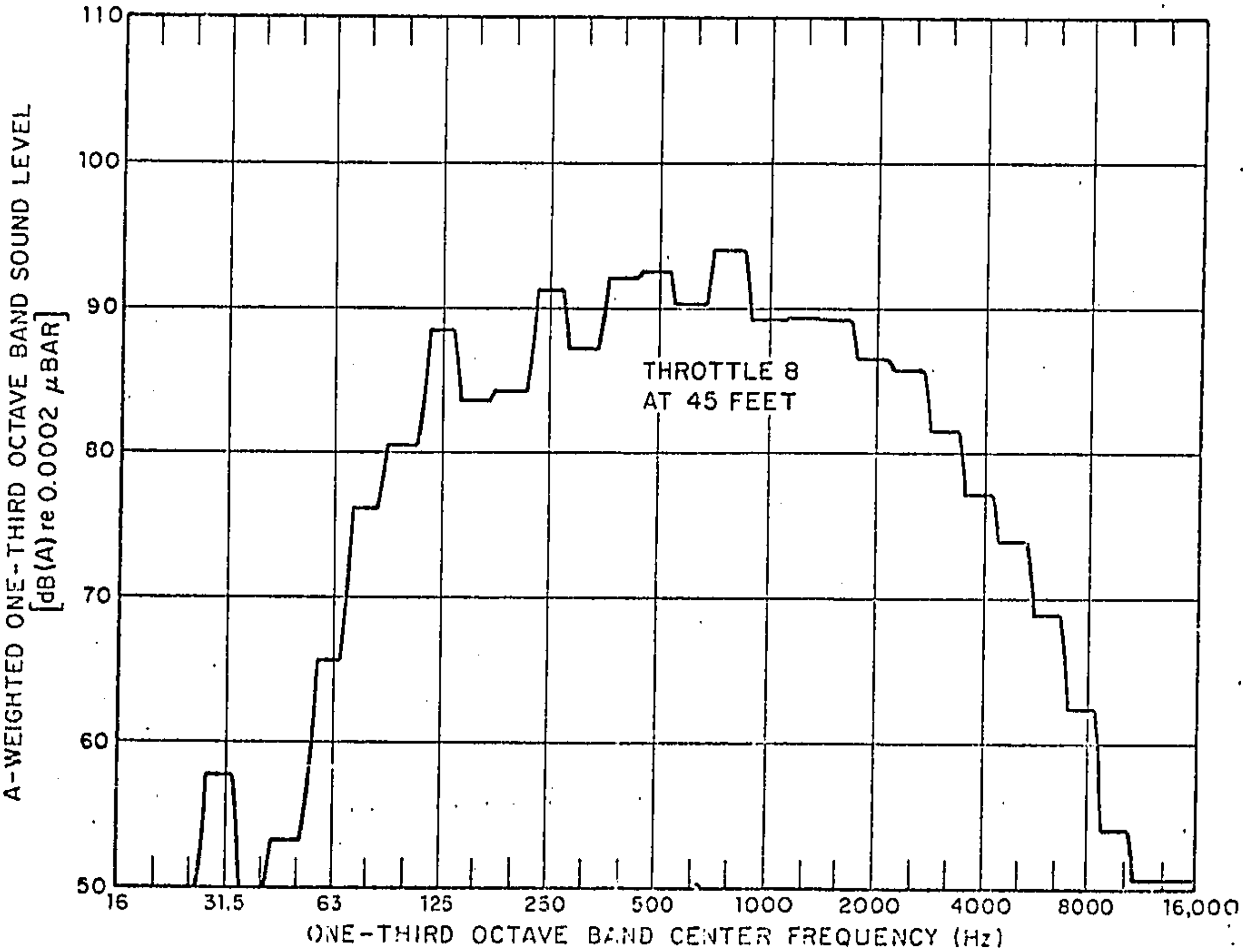

FIG. A.1.8(b) FREQUENCY ANALYSIS OF NOISE 45 FT TO THE SIDE OF A GM SW-1500 LOCOMOTIVE AT THROTTLE SETTING 8

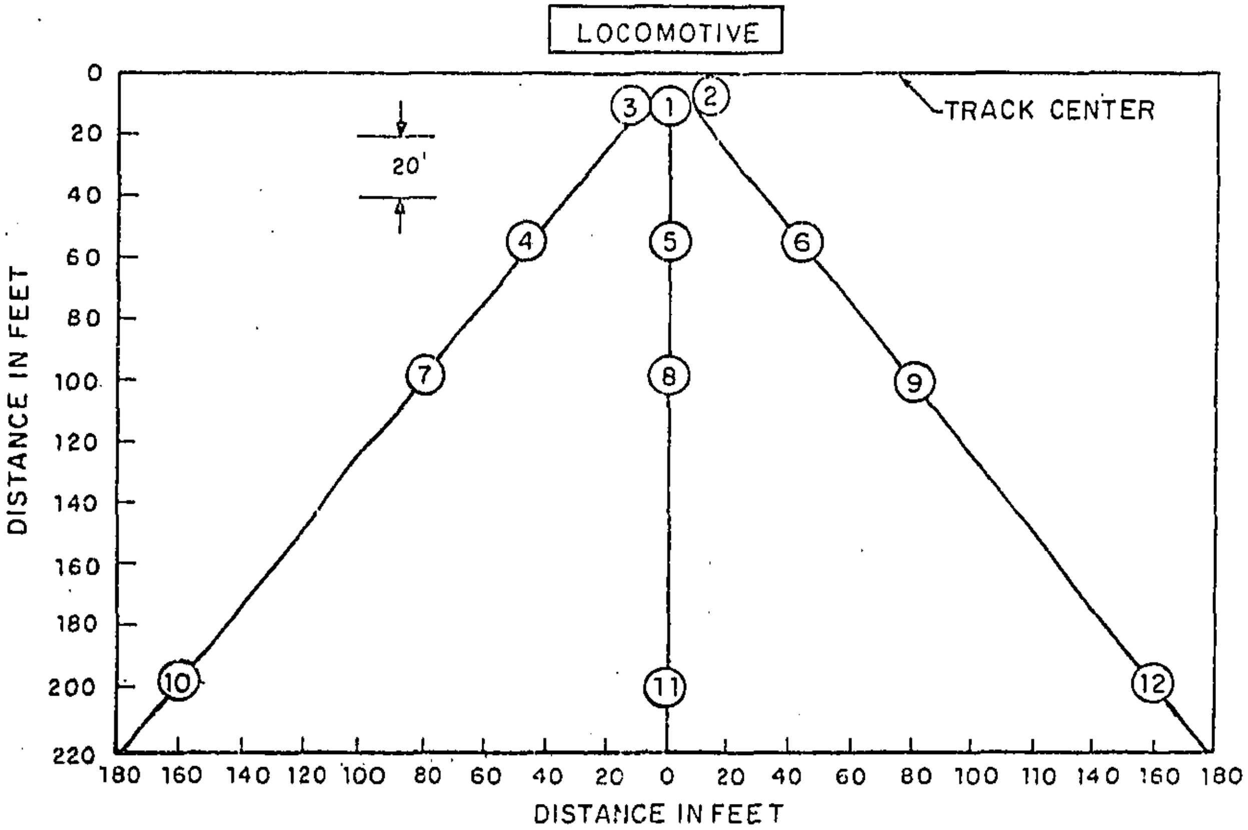

FIG. A.2.1. LOCATION OF THE MEASUREMENT POINTS AROUND A STATIONARY EMD GP40-2 (3000 hp) LOCOMOTIVE AT THE DENVER AND RIO GRANDE WESTERN BURNHAM SHOPS, DENVER, COLORADO

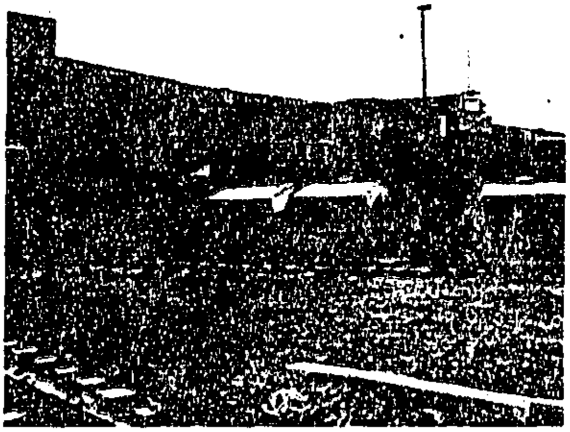

FIG. A.2.2. PHOTOGRAPH OF AN EMD GP40-2 LOCOMOTIVE ON A LOAD CELL [Looking South of West, Showing Inactive Load Cells (Active Cells Behind Locomotive) and Measurement Equipment at Position 5]

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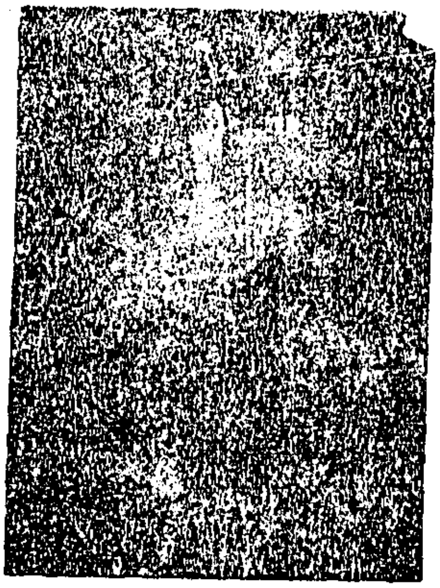
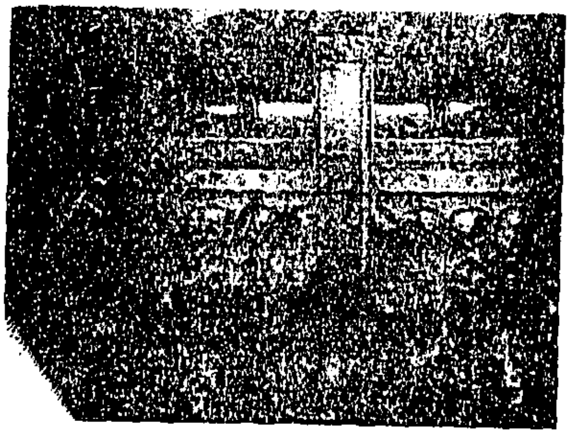


(a) Forward Compartment (No. 1) – Turbocharger and Alternator



(b) Middle Compartments (No. 2 and No. 3) – Diesel Engine

FIG. A.2.3. PHOTOGRAPHS OF THE COMPONENTS OF AN EMD GP40-2

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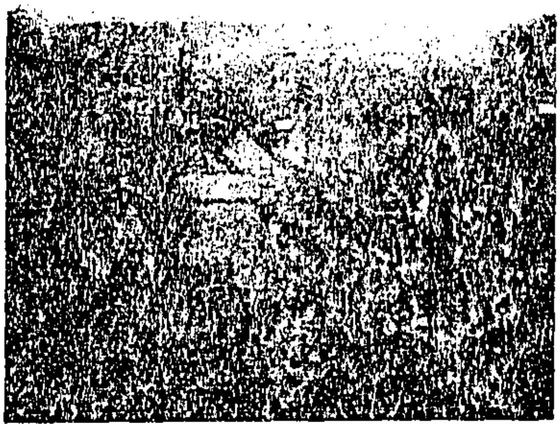
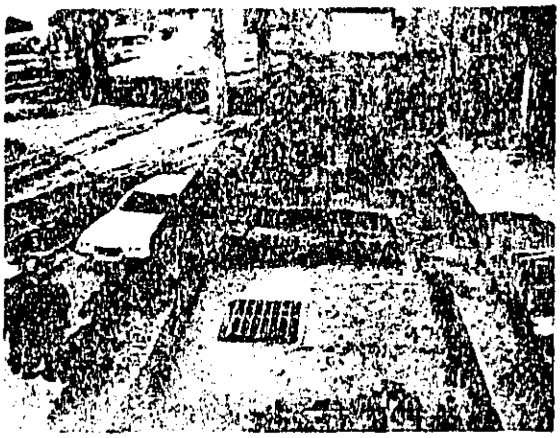


(c) Aft Compartments (No. 4, No. 5, and No. 6) – Pumps, Water Tank, Oil Cooler, and Spray Water Tank



(d) Atop the Locomotive, Looking Aft (South)

FIG. A.2.3. (CONT.)

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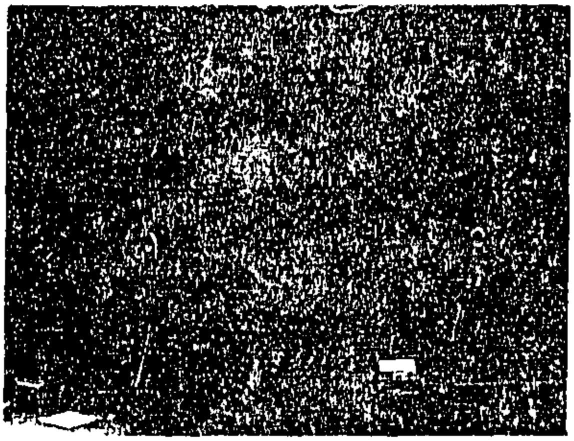
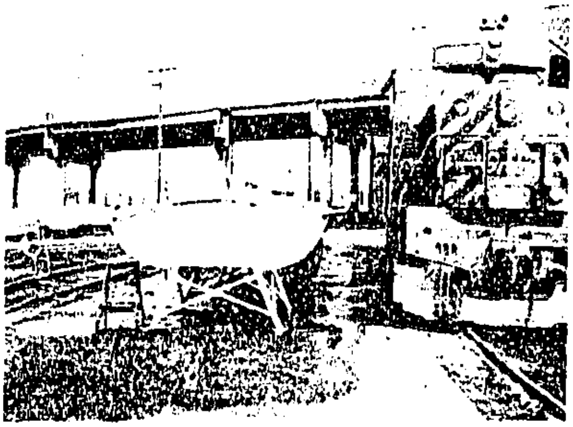


(a) Looking from Measurement Points 2 and 3 Toward the Locomotive



(b) Looking Aft (South) of Locomotive, Past Inactive Load Cells — Measurement Point 5 Shown on the Left

FIG. A.2.4. PHOTOGRAPHS OF MEASUREMENT POINTS, NOS. 2, 3, 5, 8, AND 12

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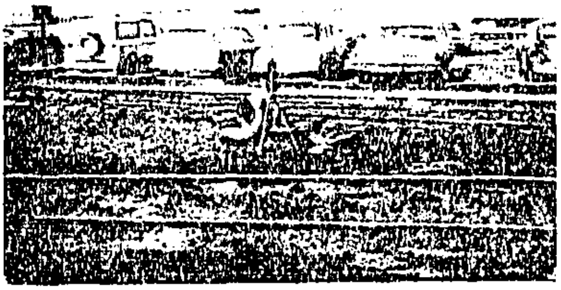
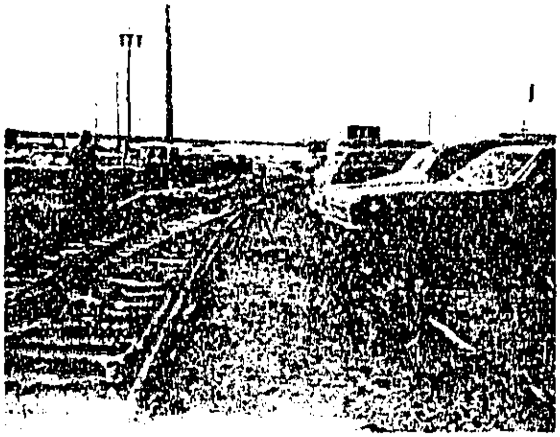


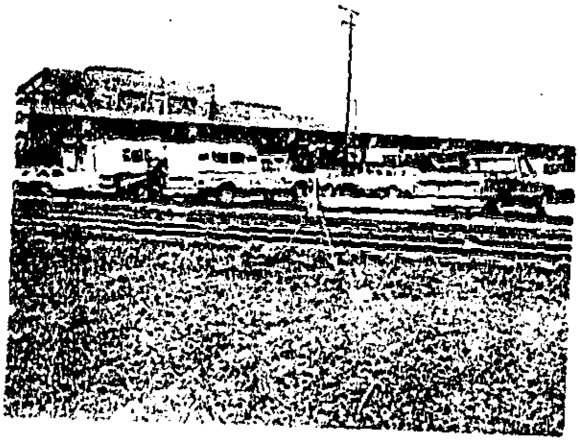
(c) Looking East, Past Measurement Point 8



(d) Looking North, Past Measurement Point 8

FIG. A.2.4. (CONT.)

(e) Looking South, Past Measurement Point 8



(f) Looking Southwest, Past Measurement Position 12

FIG. A.2.4. (CONT.)

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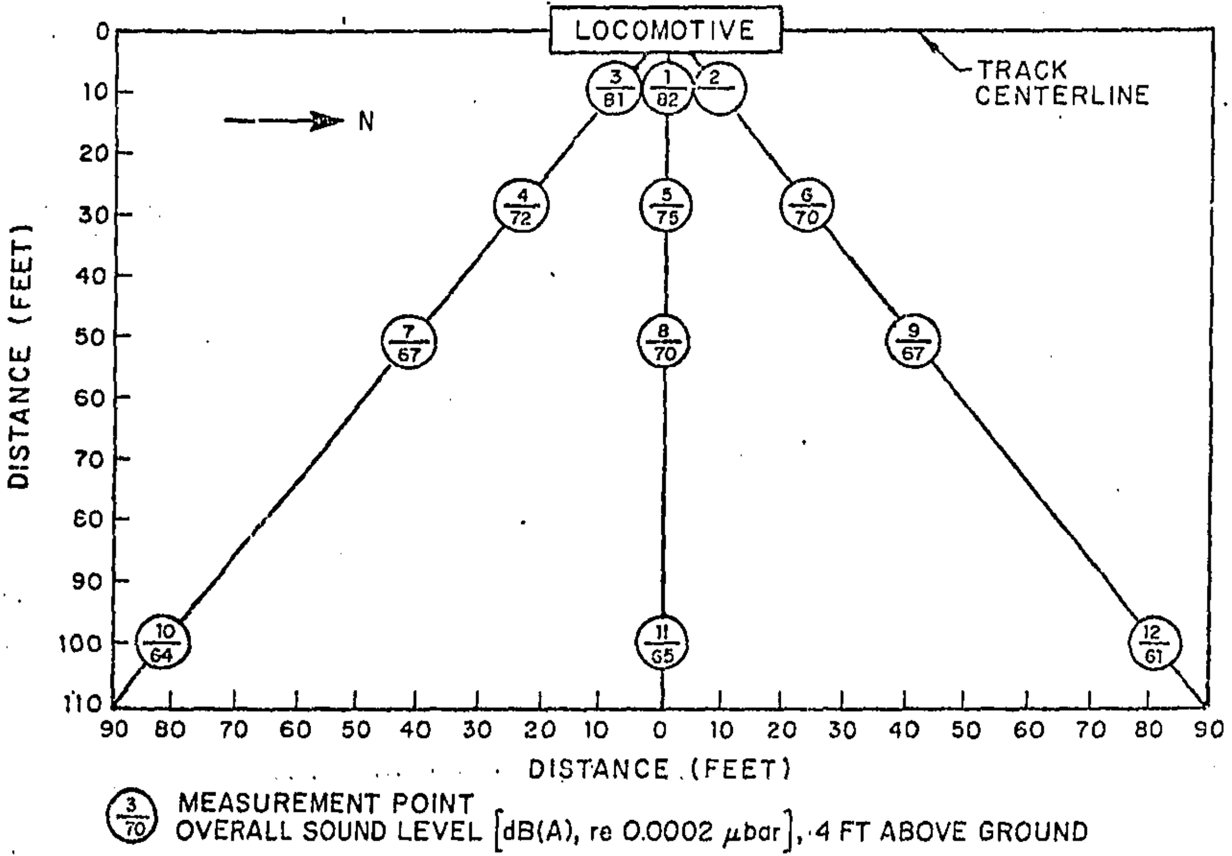

FIG. A.2.5. SOUND DISTRIBUTION AROUND A STATIONARY EMD GP40-2 (3000 hp) LOCOMOTIVE AT THROTTLE SETTING 1, MEASURED AT THE DENVER AND RIO GRANDE WESTERN BURNHAM SHOPS, DENVER, COLORADO

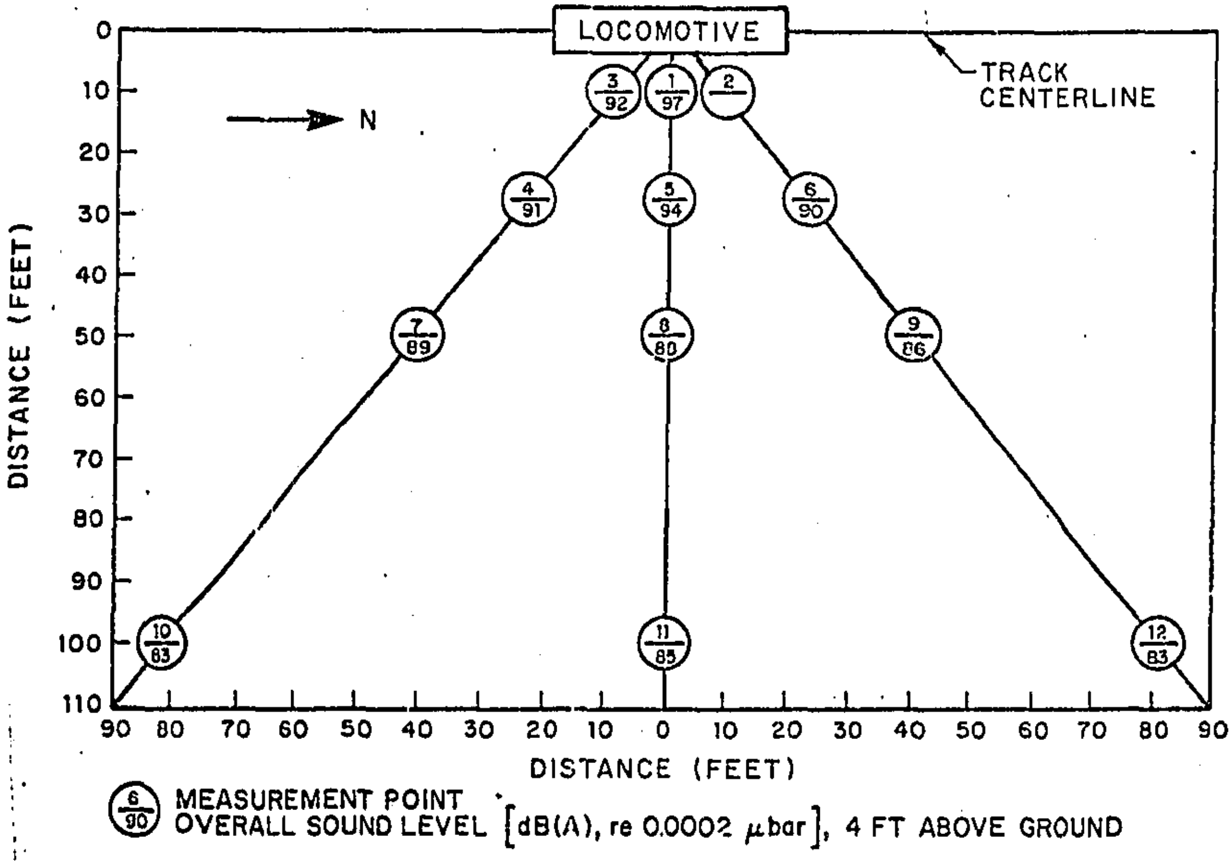

FIG. A.2.6. SOUND DISTRIBUTION AROUND A STATIONARY EMD GP40-2 (3000 hp) LOCOMOTIVE AT THROTTLE SETTING 8, MEASURED AT THE DENVER AND RIO GRANDE WESTERN BURNHAM SHOPS, DENVER, COLORADO.

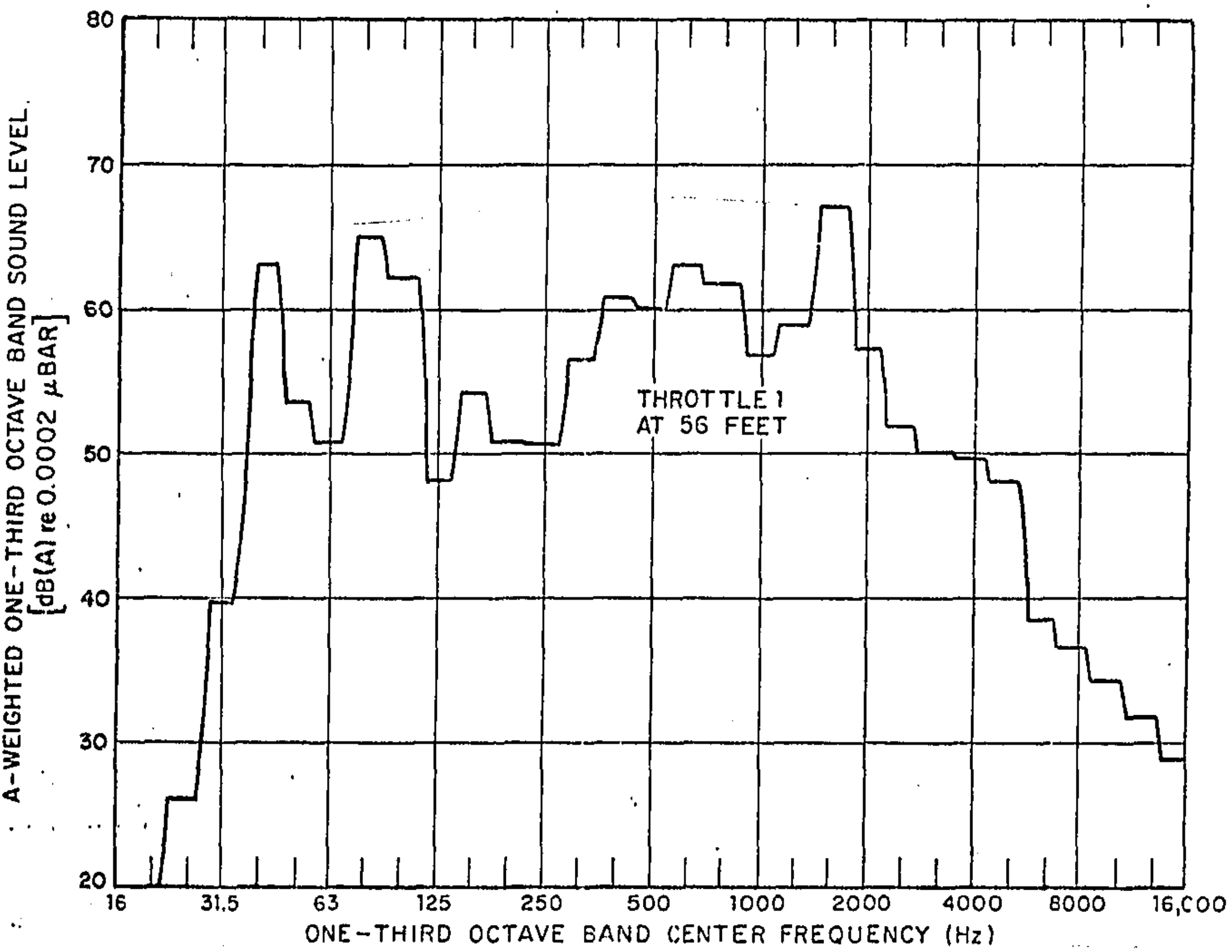

FIG. A.2.7(a) FREQUENCY ANALYSIS OF NOISE 56 FT TO THE SIDE OF AN EMD GP40-2 LOCOMOTIVE AT THROTTLE SETTING 1

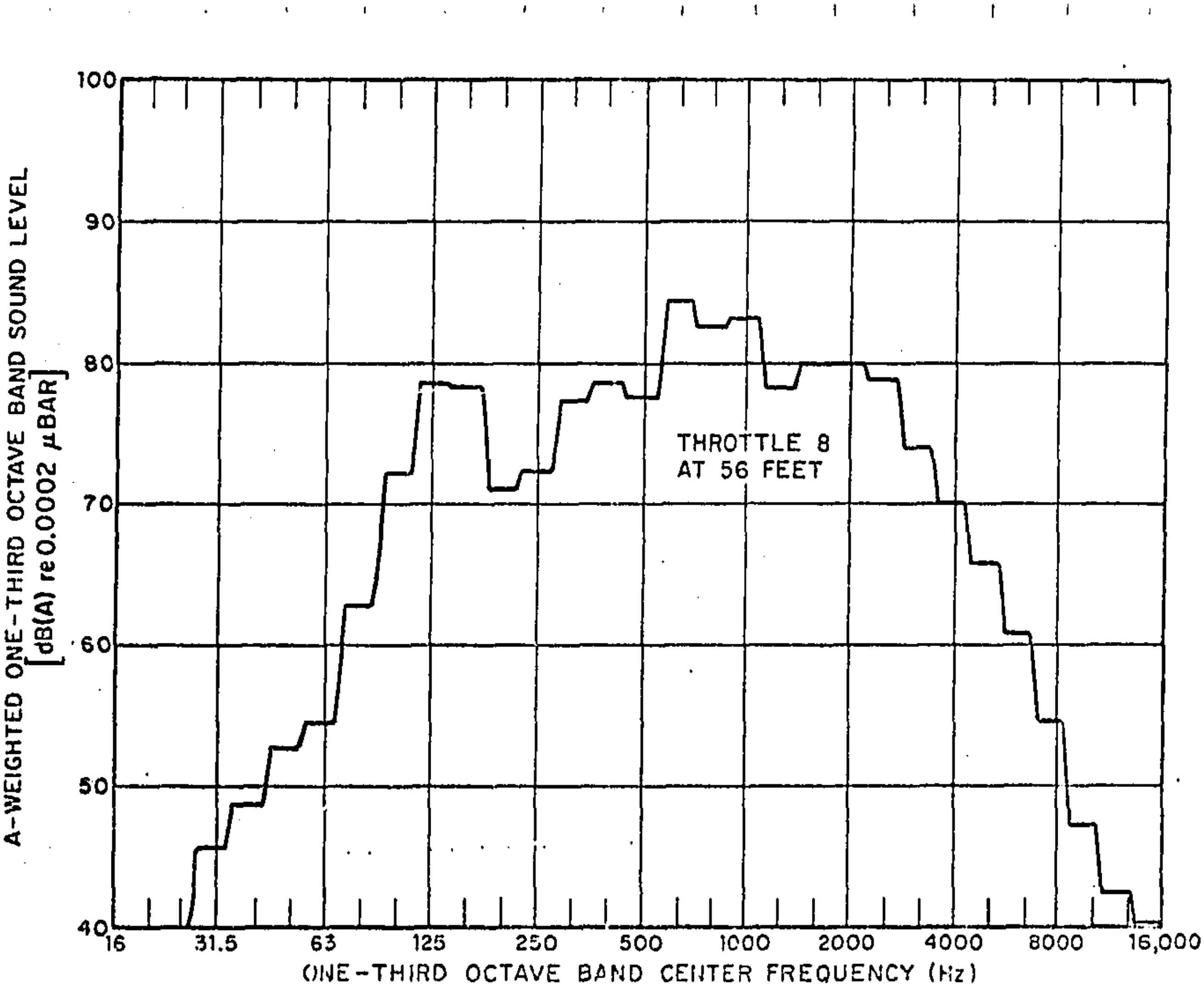

FIG. A.2.7(b) FREQUENCY ANALYSIS OF NOISE 56 FT TO THE SIDE OF AN EMD GP40-2 LOCOMOTIVE AT THROTTLE SETTING 8

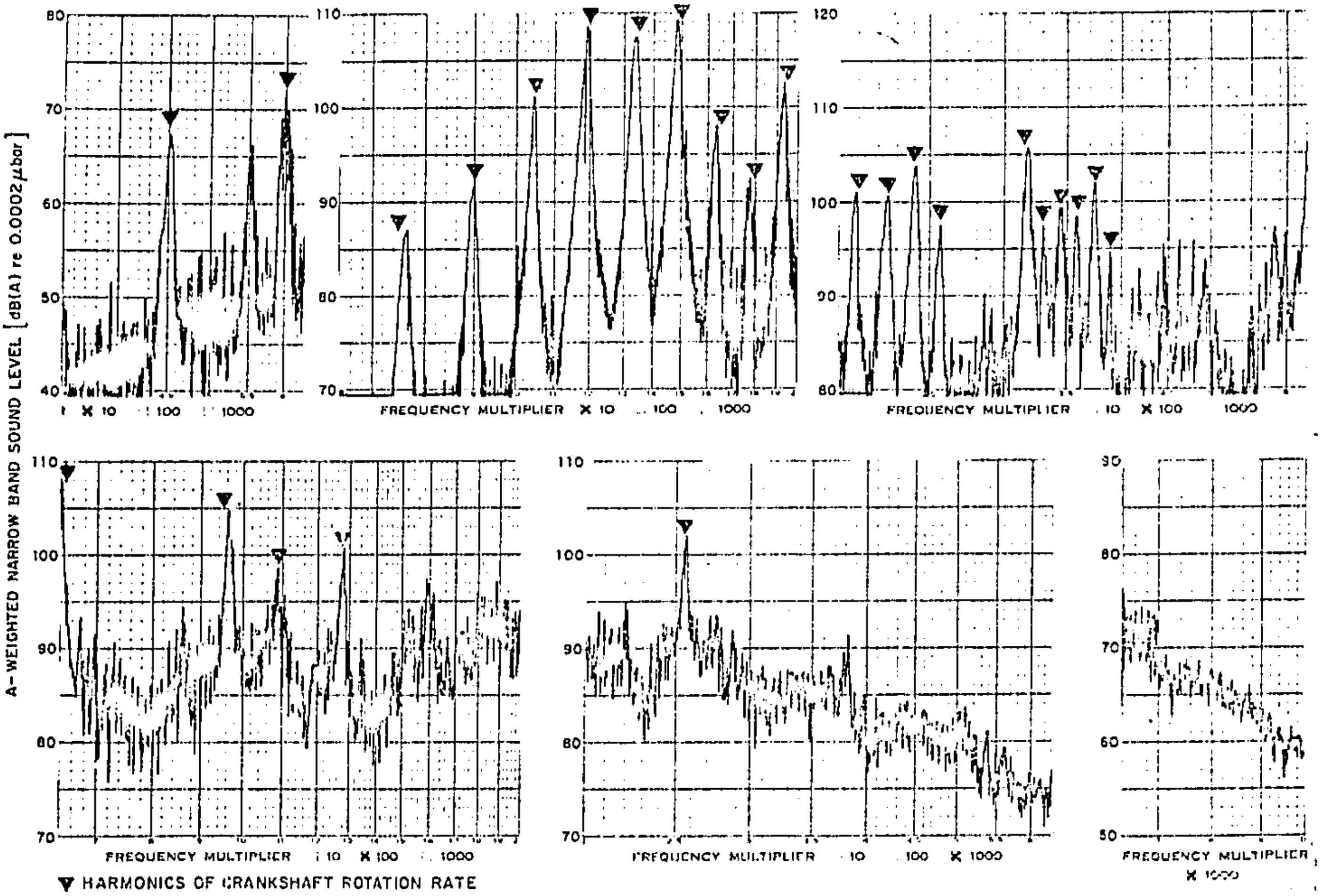

FIG. A.2.8(a) NARROW BAND FREQUENCY ANALYSIS OF EXHAUST NOISE AT 3 FT FROM THE CENTER OF THE EXHAUST OF AN EMD GP40-2 LOCOMOTIVE AT THROTTLE SETTING 8

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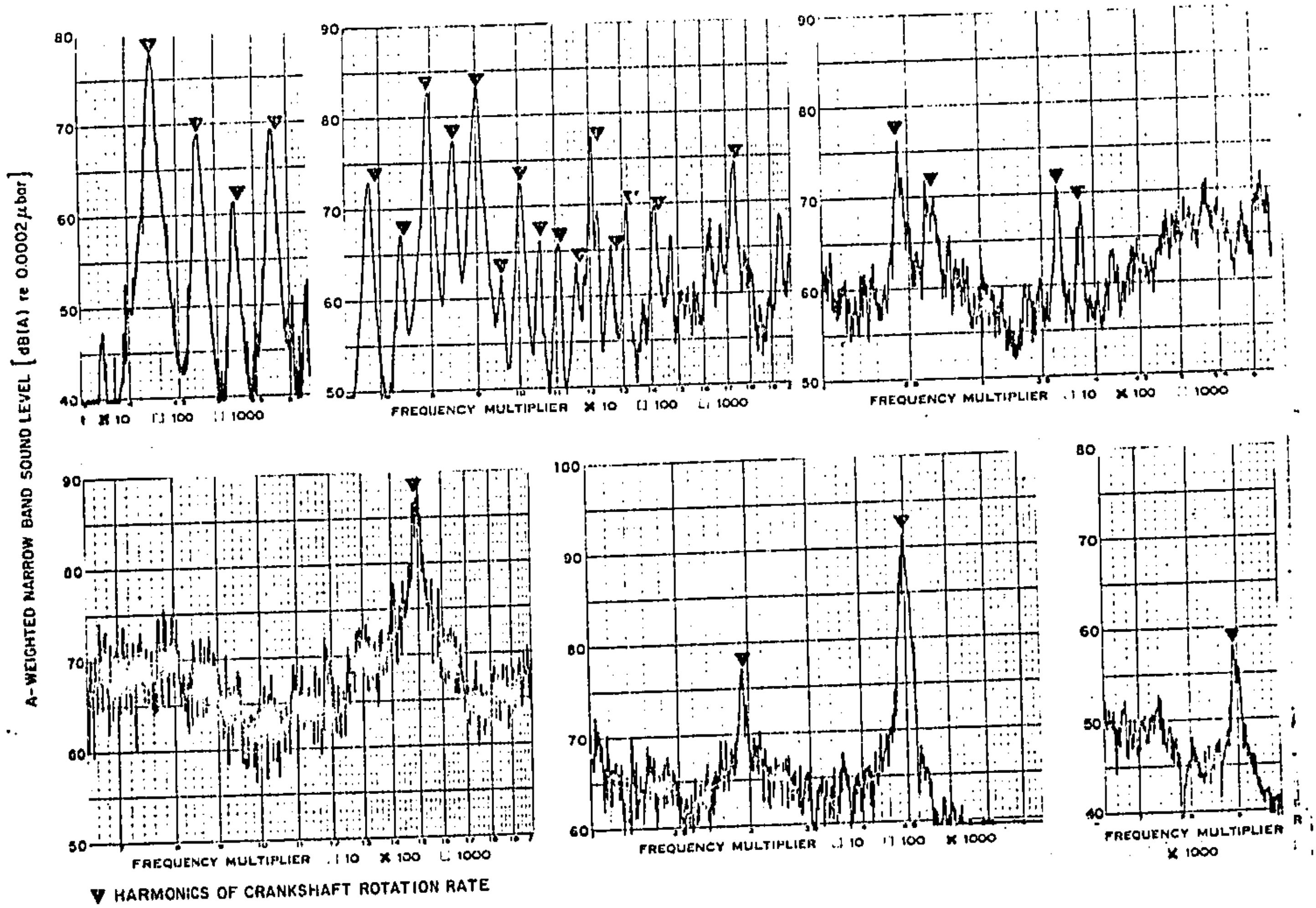

FIG. A.2.8(b) NARROW BAND FREQUENCY ANALYSIS OF EXHAUST NOISE AT 3 FT FROM THE CENTER OF THE EXHAUST OF AN EMD GP40-2 LOCOMOTIVE AT THROTTLE SETTING 1

APPENDIX B: MEASUREMENT OF WAYSIDE NOISE DUE TO TRAIN PASSAGE

B.1 One Percent Grade, Dale Street, St. Paul, Minnesota

In the afternoon of April 24 and the early morning of April 25, 1973, BBN personnel measured wayside noise near the Burlington Northern tracks, near Dale Street, in St. Paul, Minnesota.

Figure B.1.1 is a map of the test site showing two sets of tracks. Figure B.1.2 shows the profile of the grade in the vicinity of the test site. Two trains that were observed at the site were going uphill, at throttle setting 8. A third train was moving downhill with the dynamic brake activated at throttle setting 4. As the trains passed the test site, the measured noise levels were recorded on magnetic tape for later analysis.

The equipment and test procedure were the same as described in Appendix A.1. The equipment is shown in Figs. B.1.3 through B.1.7. Two microphones were located 25 ft and 300 ft away from the center of the nearest track, which carried westbound trains up the grade. The microphones were 37 ft and 312 ft away from the center of the farthest track, which carried eastbound trains down the grade. Figures B.1.3 through B.1.7 show the areas around the measurement points. The microphones were positioned 4 ft above the ground. The sound level meters were calibrated before and after the test.

The two trains moving up the grade were observed during a clear afternoon. The temperature was 62°F, and the relative humidity was 40%. The wind was blowing at 2 – 5 mph from the northeast (from the observers to the track), with gusts to 9 mph. The train moving down the grade was observed about 4:00 a.m. The temperature was 44°F, and the relative humidity was 35%. Rain had fallen earlier. The wind was blowing at 4 - 6 mph from the northeast (from observers to the track), with gusts to 8 mph.

Figures B.1.8, B.1.9, and B.1.10 show the time histories of the sound generated at the two measurement points by the passage of the trains. Figure B.1.11 shows the background noise upon which the railroad noise was superimposed. The trains are described in Figs. B.1.8, B.1.9, and B.1.10. Railroad engineers communicated with the train operators by radio in order to obtain locomotive number and type, number of cars and loading of cars, and train velocity. The train velocities were checked by measuring the time required for a given number of cars to pass a given point.

Four portions of the time histories shown in Fig. B.1.8 were selected for frequency analysis and are labeled in the figure. A sample was taken from the early portion of the records for both 25 and 300 ft to see if the known characteristics of locomotive noise dominated both records during the passage of locomotives. The corresponding spectra, shown in Figs. B.1.12 and B.1.14, are similar to spectra of measured sound from stationary locomotives. A sample was taken from the late portion of the records for both 25 and 300 ft in order to see if the characteristics of wheel/rail noise measured at 25 ft were still dominant in the noise measured at 300 ft. The corresponding spectra, shown in Figs. B.1.13 and B.1.15, show that it is possible to distinguish wheel/rail noise from locomotive noise at 300 ft as easily as at 25 ft.

The measured values of wayside noise at the Dale St. site fall within the range of other published measurements shown in Fig. 2.1. The point for the noise level due to locomotives descending the grade at Dale St. is on the low side of the levels shown for locomotives in Fig. A.1, because the throttles were at setting 4 and the locomotive engines were not developing full power.

B.2 Flat Grade, Elk River, Minnesota

On April 25, 1973, BBN personnel measured wayside noise near the Burlington Northern tracks, west of Elk River, Minnesota (Mile Post 41 + 2454). There are two sets of tracks at the test site. Five trains were observed moving past the Elk River site — four freights and one passenger train. The throttles of all of the locomotives were at setting 8.

The instrumentation and the test procedure were the same as described in Appendix A.1. Figures B.2.1 and B.2.2 show the measurement configuration and the landscape around the measurement points. Two microphones were located 50 and 300 ft away from the center of the farthest track, which carried westbound trains. The microphones were 38 and 288 ft away from the center of the nearest track, which carried eastbound trains.

The measurements were made on a clear night. The temperature was 48°F, and the relative humidity was 26%. The wind varied from imperceptible to 4 mph, and the direction shifted frequently.

Figures B.2.3 through B.2.7 show the time histories of the sound generated at the two measurement points by the passage of the trains, which are described in Figs. B.2.3 through B.2.7. Railroad engineers communicated with train operators by radio in order to obtain the operating characteristics of the trains. The train velocities were checked by measuring the time required for a given number of cars to pass a given point.

Eight intervals of the time histories shown in Fig. B.2.7 were selected for frequency analysis, and are labeled in the figure. A sample was taken from the early portion of the records for both 38 ft and 288 ft to see if the known characteristics of locomotive noise dominated both records. The corresponding spectra, shown in Figs. B.2.8 and B.2.10, are similar to spectra of measured sound from stationary locomotives. Three samples were taken from the later portion of each of the records for 38 ft and 288 ft to see if the characteristics of the wheel/rail noise measured at 25 ft changed in time or in space. The corresponding spectra, shown in Figs. B.2.9 and B.2.11, show that wheel/rail noise can be distinguished from locomotive noise at both 38 ft and 288 ft, and the characteristics of the wheel/rail noise did not vary much with time at either 38 ft or 288 ft.

The measured values of wayside noise at the Elk River site fall within the range of other published measurements shown in Fig. 2.1.

B.3 Two Percent Grade, Leyden, Colorado

On May 3, 1973, BBN personnel measured wayside noise near the Denver and Rio Grande Western track, at mile-point 14.7 between Leyden and Rocky, about 15 miles west of Denver on the main line between Denver and Grand Junction, Colorado. Figure B.3.1 is a map of the area surrounding the test site. Figure B.3.2 shows the profile of the grade in the vicinity of the test site. Five trains were observed moving past the Leyden test site — three freights, a passenger train, and two coupled locomotives without cars.

The instrumentation and the test procedure were the same as described in Appendix A.1. Figures B.3.3 through B.3.6 show the configuration of the equipment. Two microphones were located 25 ft and 500 ft from the center of the track. Figures B.3.3 and B.3.6 show the landscape around the measurement points.

The first four trains were observed during a clear morning. The temperature was 53°F, the ground was partially covered by snow, and the relative humidity was 47%. The wind was blowing steadily at 3 mph from the west (parallel to the track). The fifth train was observed about 4:00 p.m. The temperature was 69°F. The relative humidity was 19%. All of the snow on the ground had melted. The wind was blowing at 1 or 2 mph from the northeast (away from the observers, toward the track).

Figures B.3.7 through B.3.11 show the time histories of the sound generated at the two measurement points by the passage of the trains. The trains are described in those figures. The operating characteristics of the trains were obtained from the locomotive serial numbers and from the run times by referring to the railroad company's records of the runs. The train velocities were determined by measuring the time required for a given number of cars to pass a given point.

Three intervals of the time history of sound level at 25 ft shown in Fig. B.3.11 were selected for frequency analysis, and the three selected intervals are labeled in the figure. A sample was taken from the early portion of the record in order to see if the known characteristics of locomotive noise dominated the record during the passage of locomotives. The corresponding spectrum, shown in Fig. 3.12, is similar to spectra of measured sounds from stationary locomotives. Two later samples were taken to see if the characteristics of wheel/rail noise changed during passage from a steady "well-behaved" region into a "poorly-behaved" region of rapidly varying and unusually high noise levels. Figure B.3.13 shows that the shape of the spectrum of wheel/rail noise did not change significantly when the unusually high noise levels occurred.

Both the locomotive noise and the wheel/rail noise measured at Leyden are high compared to the other measured values shown in Fig. 2.1. The magnetic tape recordings of the wayside noise and the graphic level printouts of the time history of the sound pressure level have been checked repeatedly for error, and none has been detected. A horn blast, shown in Fig. B.3.7, provided a very good check of the calibration. The measured levels for the horn sound agree very well with point source spreading, which adds confidence to the unusually high measured values for wayside noise.

Figure B.3.1 shows that the track was curved in the vicinity of the measurement site. That curvature may account for the high wheel/rail noise, since the flanges of the car wheels may have been rubbing against the rails. The resultant loading of the locomotives, added to the already heavy loading due to the relatively steep grade, probably caused the radiator cooling fans to switch on. That would account for the high locomotive noise.

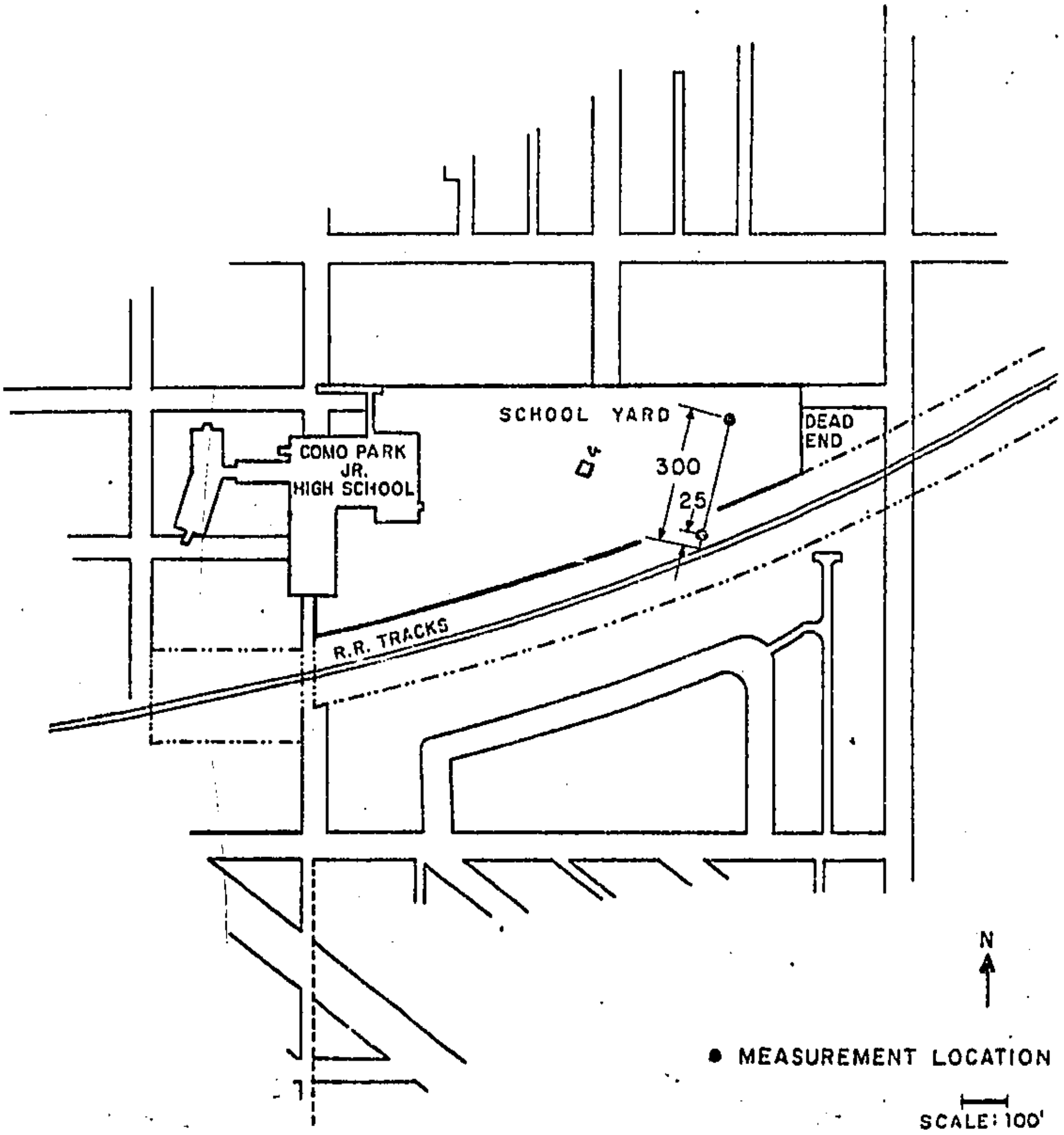

FIG. B.1.1. A MAP OF THE VICINITY OF THE DALE STREET GRADE

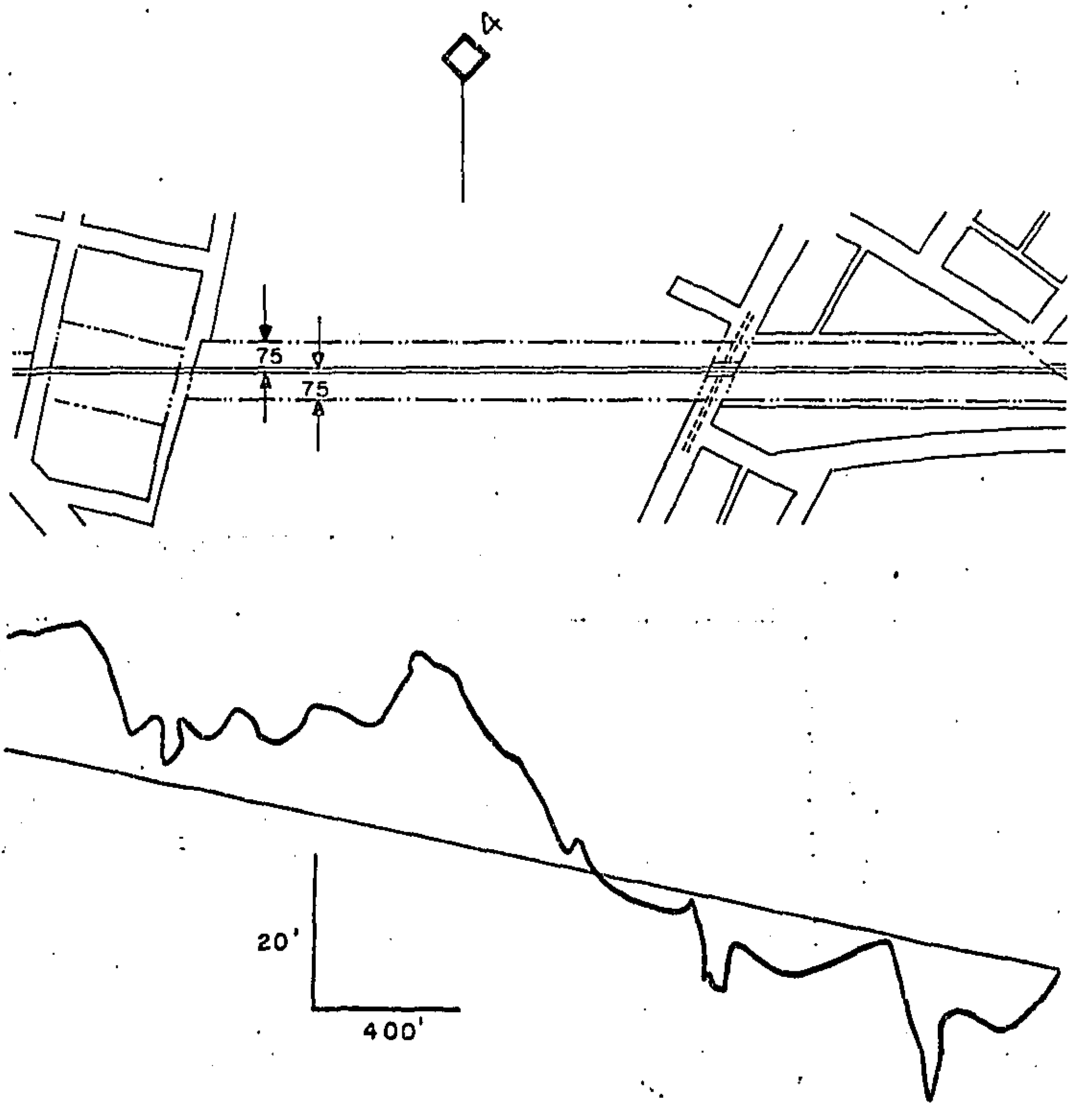

FIG. B.1.2. TRACK PROFILE AT AND NEAR THE DALE STREET GRADE

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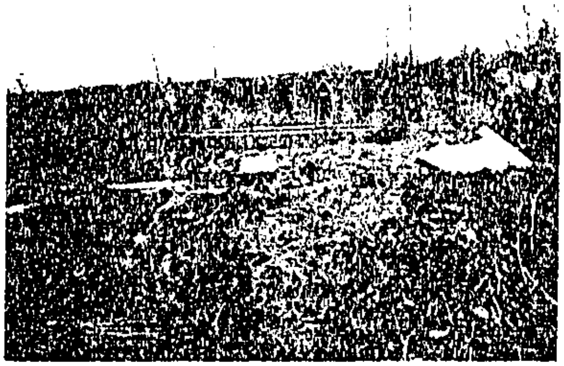
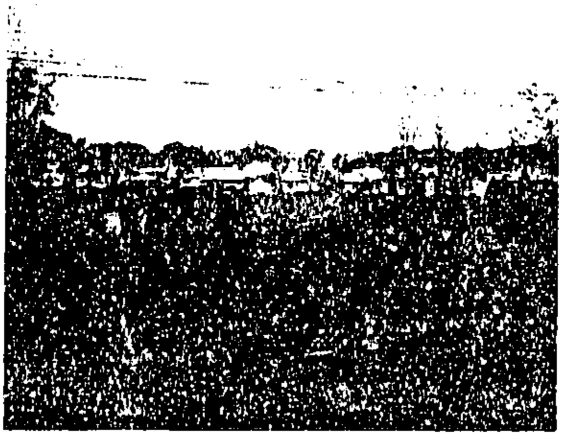


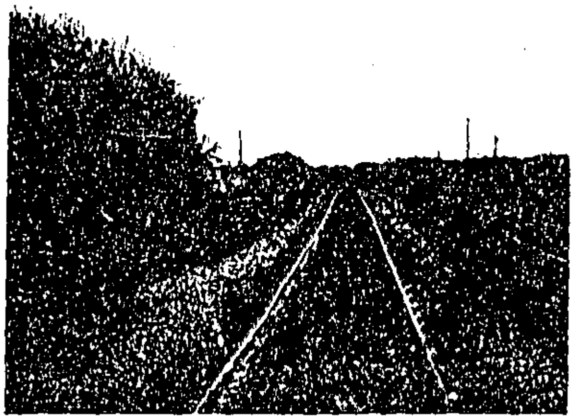
(a) Near Field Measurement Point, Looking South Toward Tracks



(b) Looking North, into Community, Toward Far Field Measurement Point

FIG. B.1.3. PHOTOGRAPHS OF THE DALE STREET NEAR FIELD MEASUREMENT POINT

(c) Looking West, up the Grade, from a Point South of the Near Field Measurement Point



(d) Looking East, Down the Grade

FIG. B.1.3. (CONT.)

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(e) Looking Northwest, Toward a School, from the Near Field Measurement Point

FIG. B.1.3. (CONT.)

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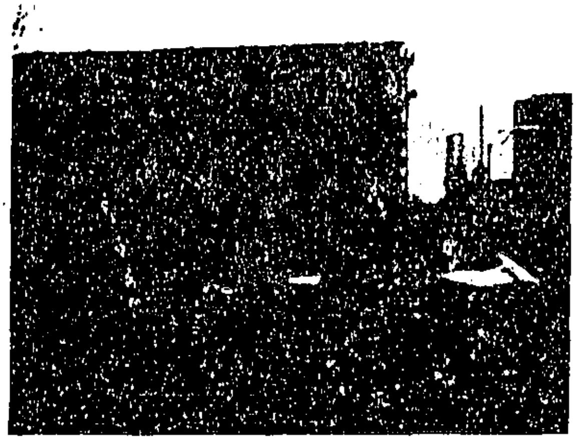
(a) Train No. 6, Headed West, Upgrade

(b) Train No. 6, Headed West, Upgrade

FIG. B.1.4. PHOTOGRAPHS OF TRAIN NO. 6 PASSING THE DALE STREET NEAR FIELD POINT



(c) Train No. 6, Headed West, Upgrade

FIG. B.1.4. (CONT.)

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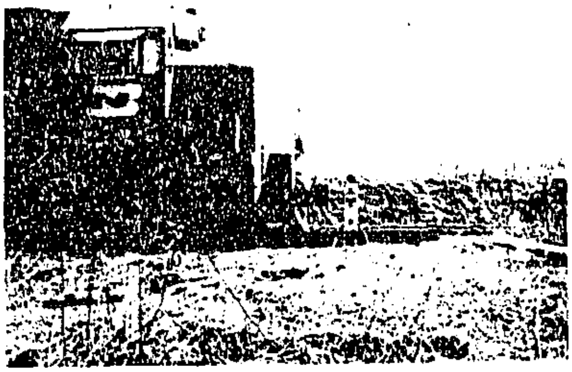
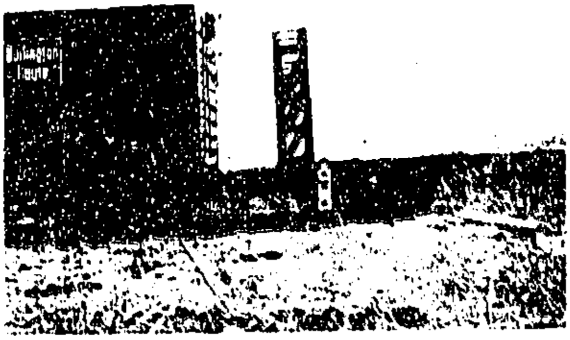


(a) Train No. 7, Headed West, Upgrade



(b) Train No. 7, Headed West, Upgrade

FIG. B.1.5. PHOTOGRAPHS OF TRAIN NO. 7 PASSING THE DALE STREET NEAR FIELD POINT

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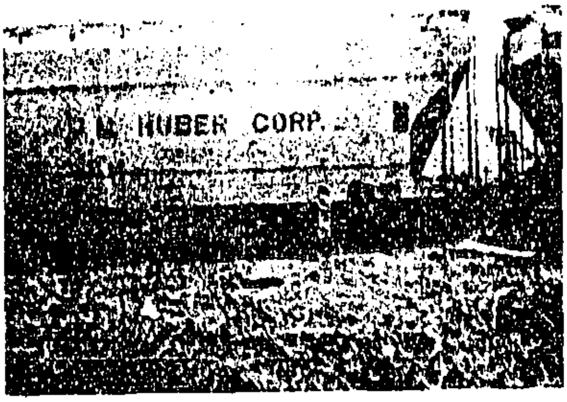

(c) Train No. 7, Headed West, Upgrade

(d) Train No. 7, Headed West, Upgrade

FIG. B.1.5. (CONT.)

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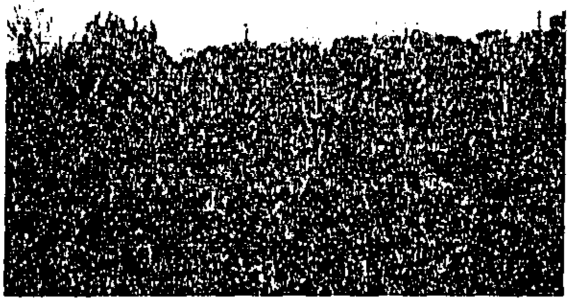

(a) Far Field Measurement Point, Looking South Toward Tracks

(b) Far Field Measurement Point, Looking East

FIG. B.1.6. PHOTOGRAPHS OF THE DALE STREET FAR FIELD MEASUREMENT POINT

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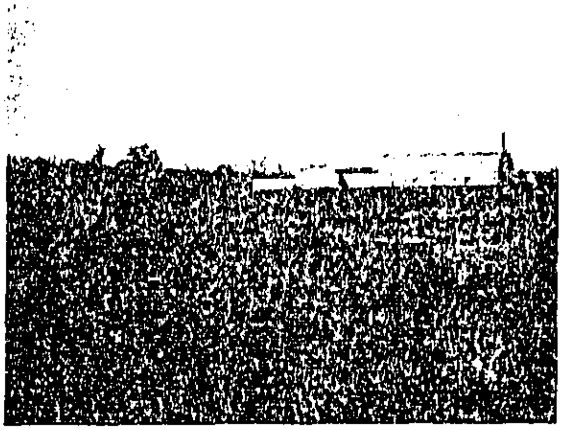
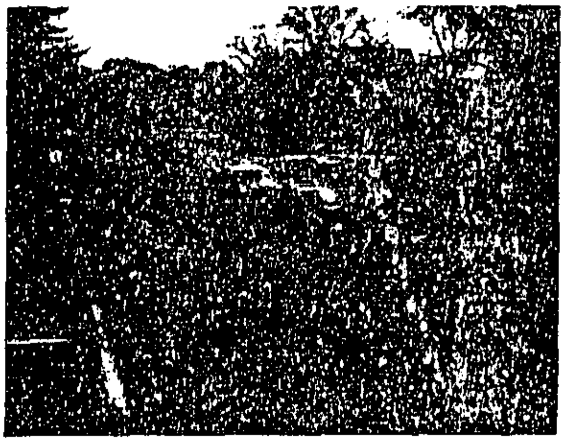


(c) Far Field Measurement Point, Looking West, Toward a School



(d) Looking East into the Community from a Point North of the Far Field Measurement Point

FIG. B.1.6. (CONT.)

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(a) Train No. 7, Approaching the Test Area (Viewed from the Far Field Measurement Point)

(b) Train No. 7, Opposite the Two Test Sites

FIG. B.1.7. PHOTOGRAPHS OF TRAIN NO. 7 FROM THE DALE STREET FAR FIELD POINT

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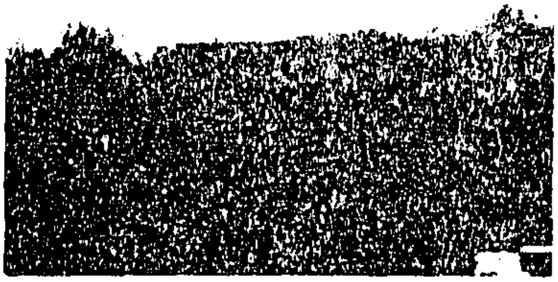

(c) Train No. 7, Opposite the Two Test Sites

(d) Train No. 7, Leaving the Test Area (Viewed from the Far Field Measurement Point)

FIG. B.1.7. (CONT.)

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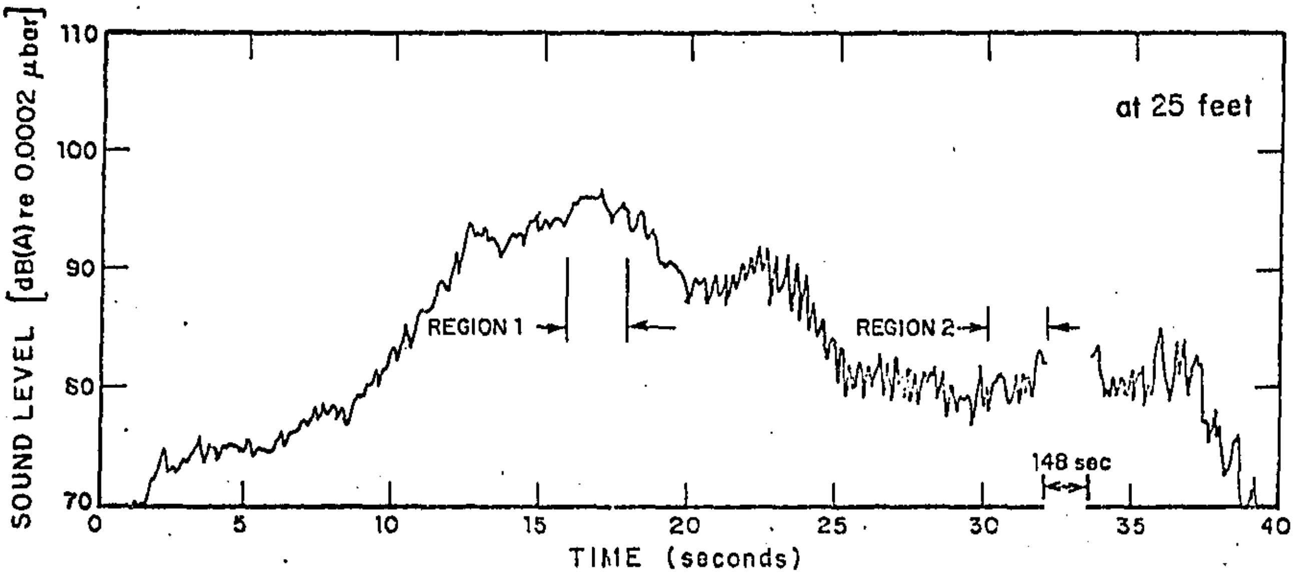

FIG. B.1.8. TRAIN NO. 6, FREIGHT, 10,850 hp (EMD SD-45, EMD SD-40, GE U25C, EMD GP 9), 77 CARS (3500 TONS) CLIMBING A 1% GRADE AT 20 mph (NO. 8 THROTTLE)

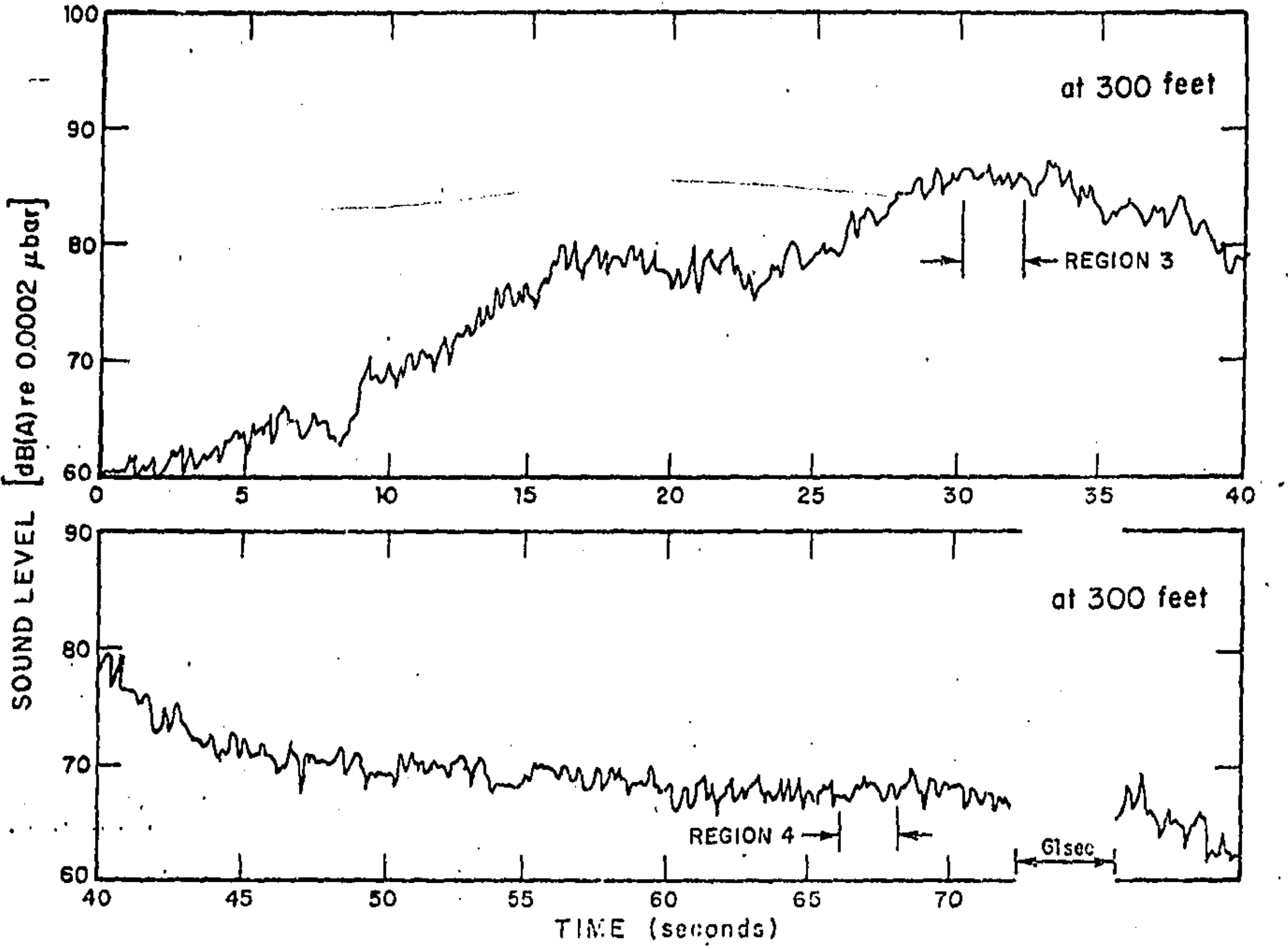
100
90
80
70
60
at 300 feet
REGION 3
0
5
10
15
20
25
30
35
40
SOUND LEVEL [dB(A) re 0.0002 μbar]
90
80
70
60
at 300 feet
REGION 4
61sec
40
45
50
55
60
65
70
TIME (seconds)

FIG. B.1.8. (CONT.)

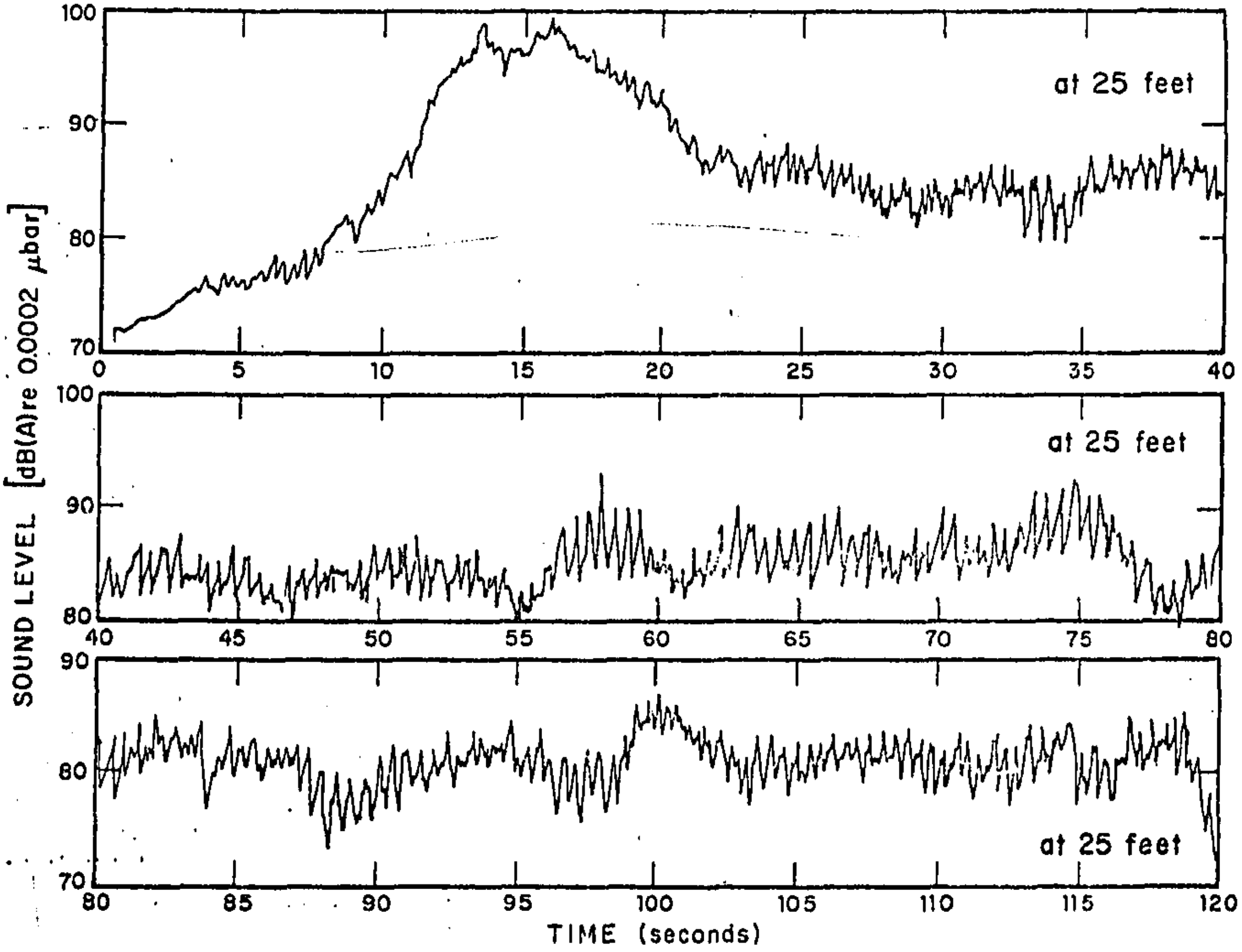

FIG. B.1.9. TRAIN NO. 7, FREIGHT, 10,800 hp (3 EMD SD-45's), 81 CARS (3458 TONS) CLIMBING A 1% GRADE AT 29 mph (THROTTLE 8).

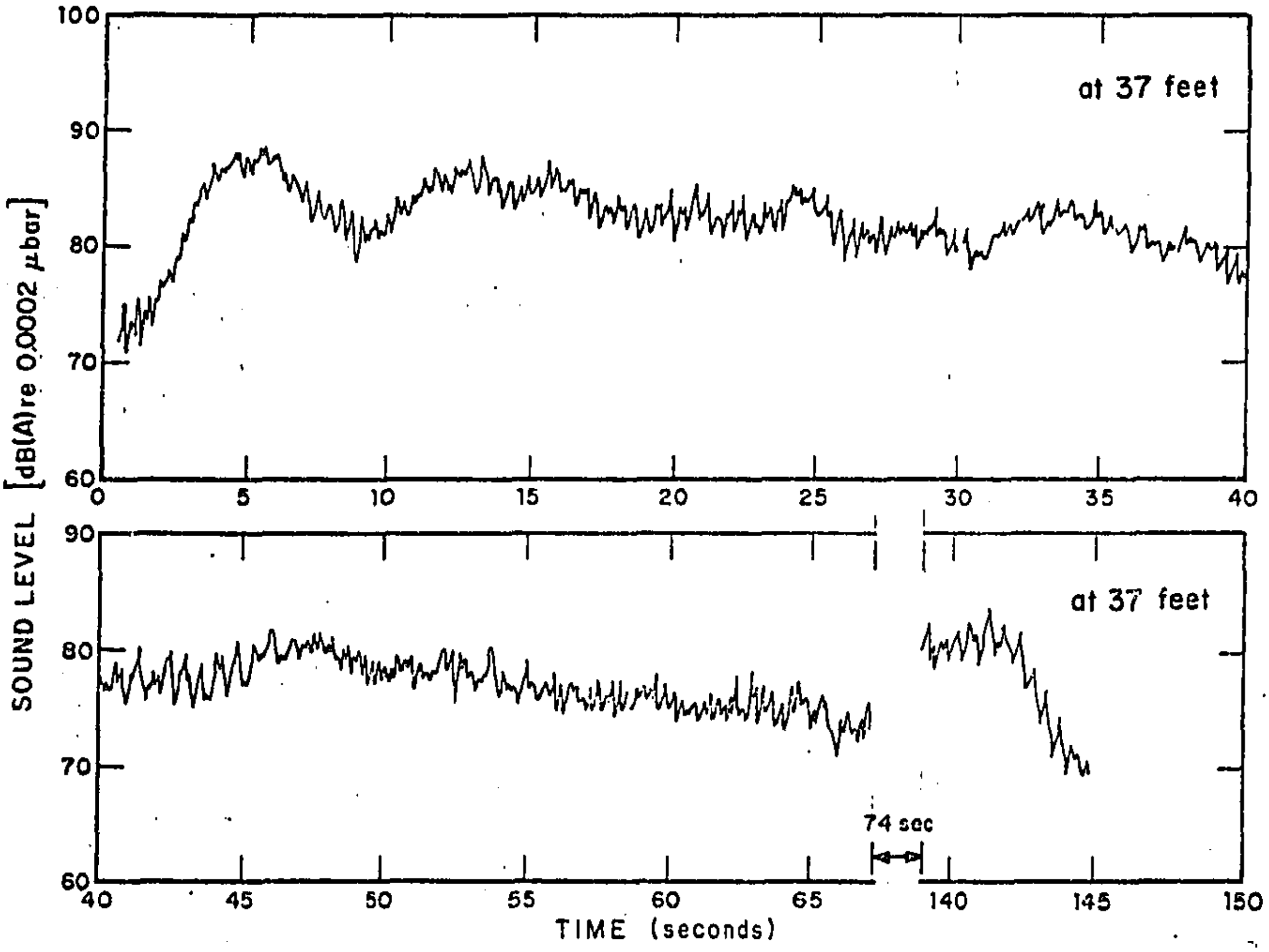

FIG. B.1.10. TRAIN NO. 8, FREIGHT, 5250 hp (3 EMD F-9's), 88 CARS (4787 TONS) GOING DOWN A 1% GRADE AT 22 mph (THROTTLE 4, WITH DYNAMIC BRAKE)

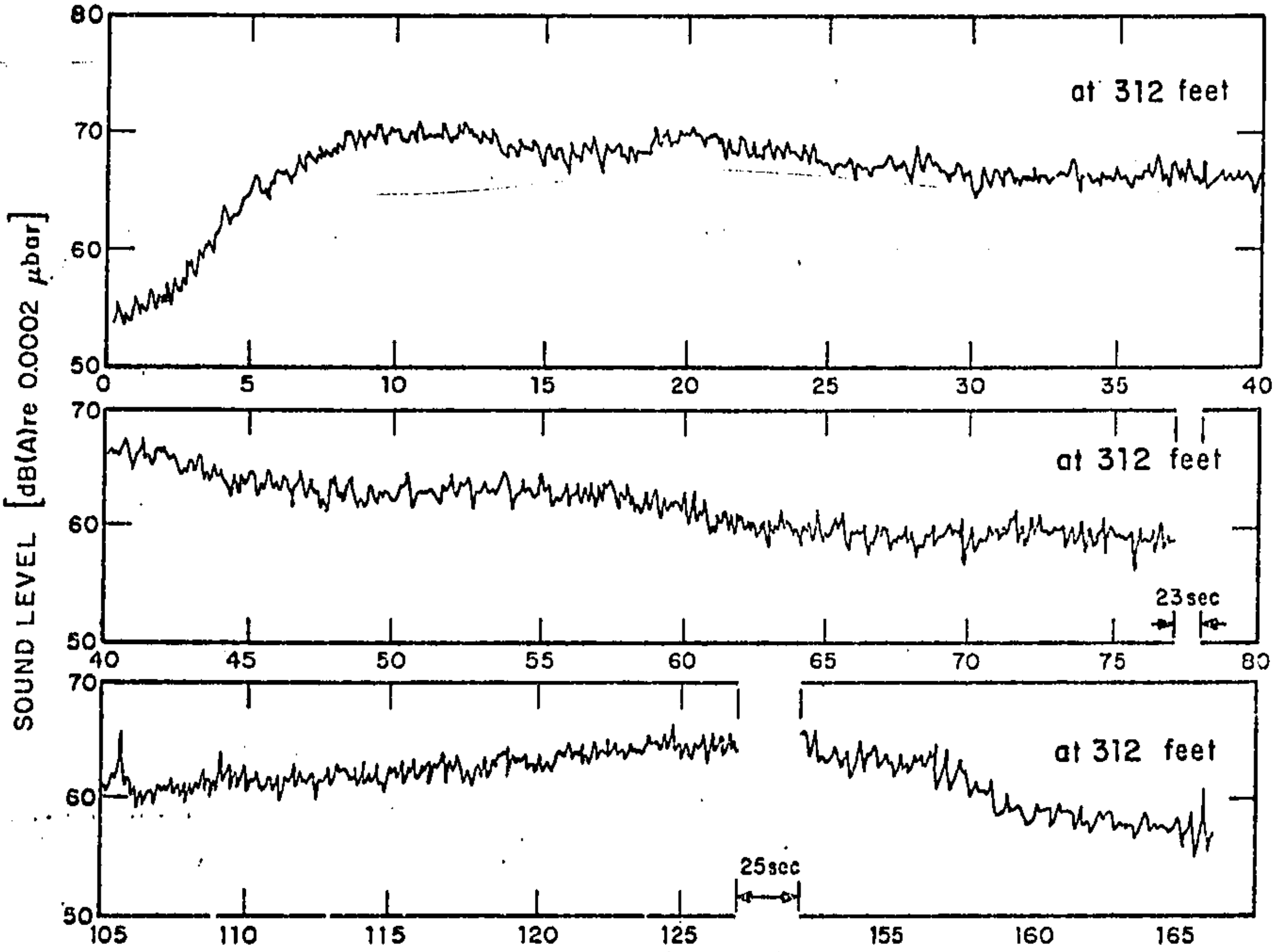

FIG. B.1.10. (CONT.)

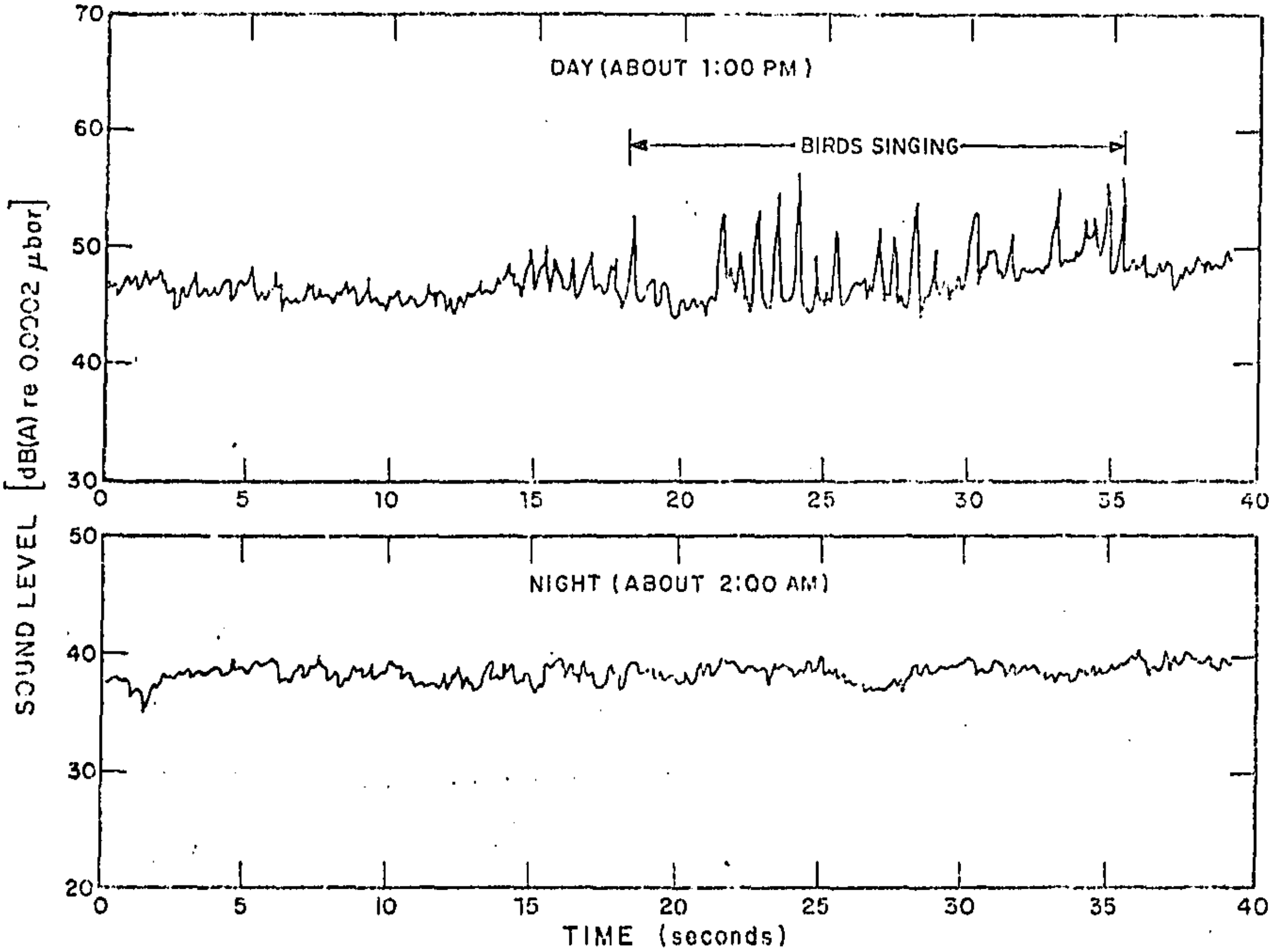

FIG. B.1.11. BACKGROUND NOISE AT THE DALE STREET TEST SITE

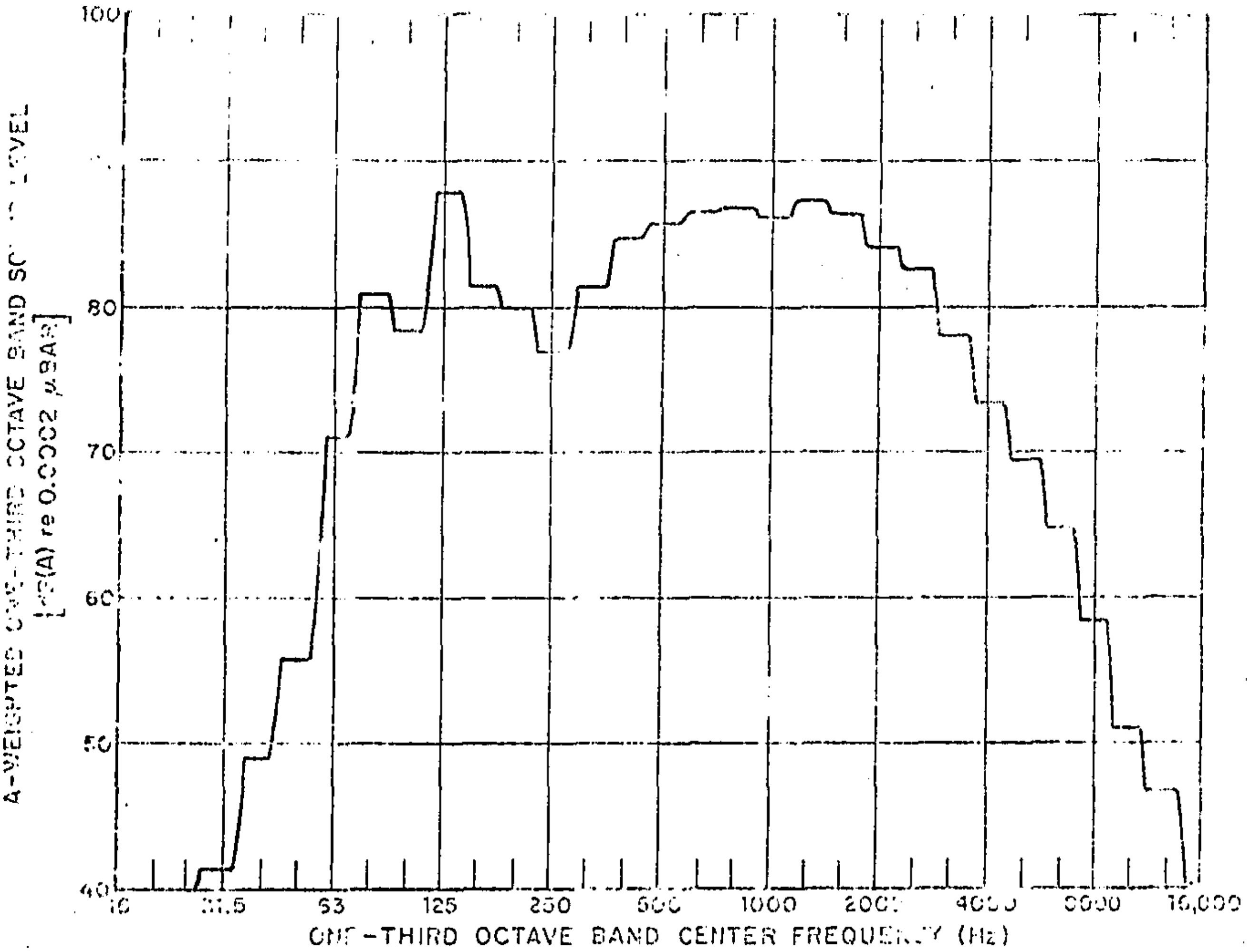

FIG. [illegible].1.12: FREQUENCY ANALYSIS OF EARLY PORTION (REGION 1) OF TRAIN NO. 6 NOISE AT 25 FT

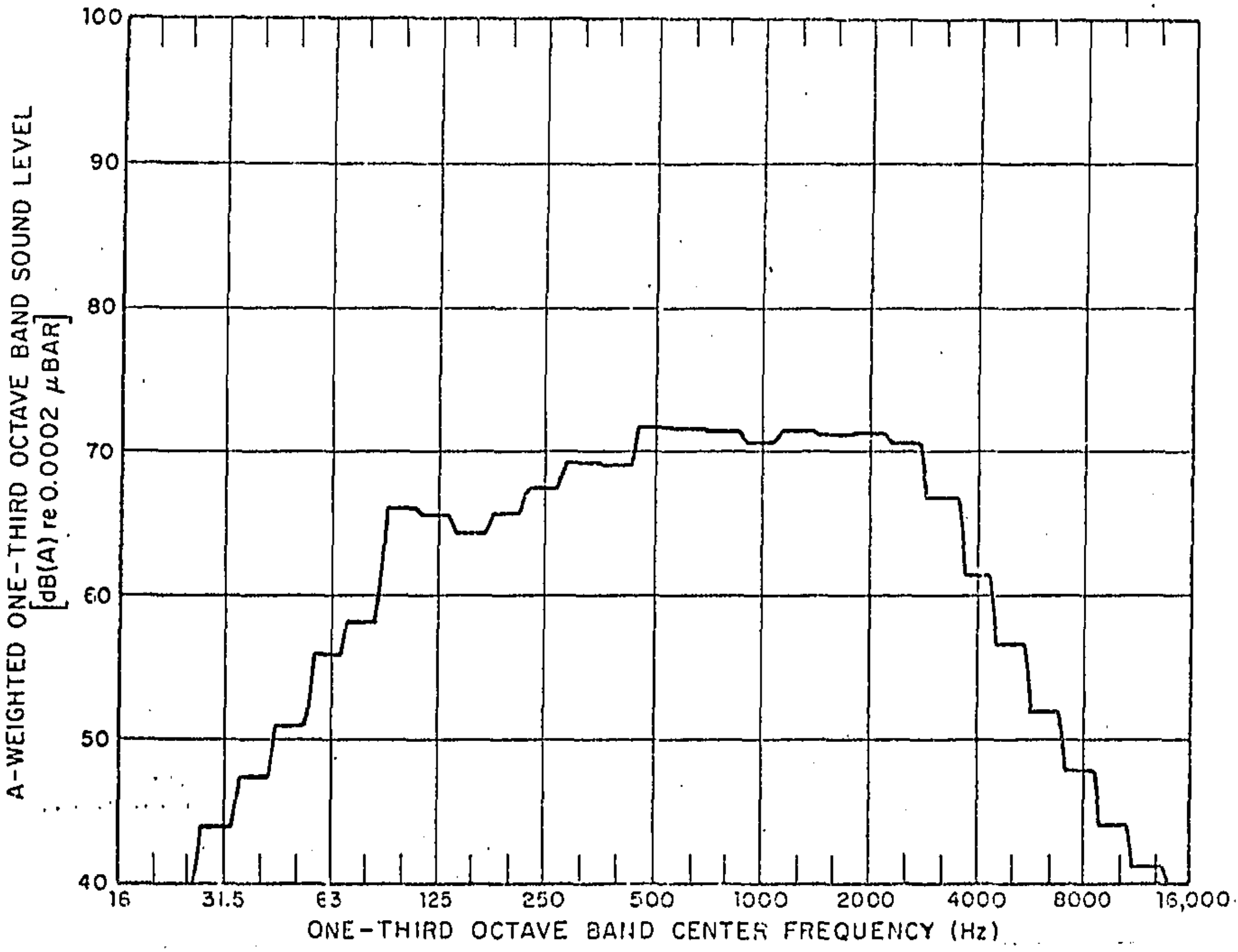

FIG. B.1.13. FREQUENCY ANALYSIS OF LATE PORTION (REGION 2) OF TRAIN NO. 6 NOISE AT 25 FT

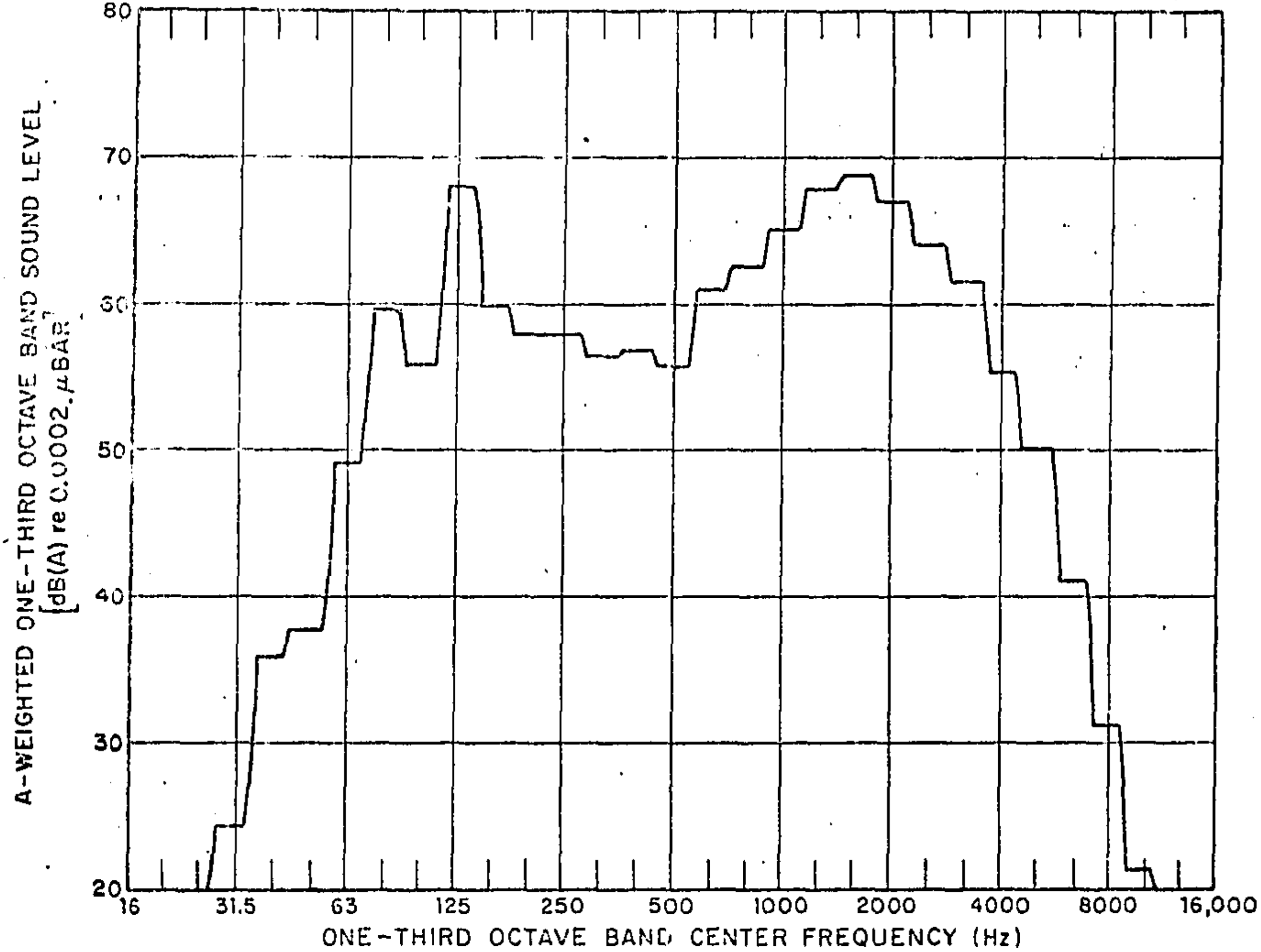

FIG. B.1.14. FREQUENCY ANALYSIS OF EARLY PORTION (REGION 3) OF TRAIN NO. 6 NOISE AT 300 FT

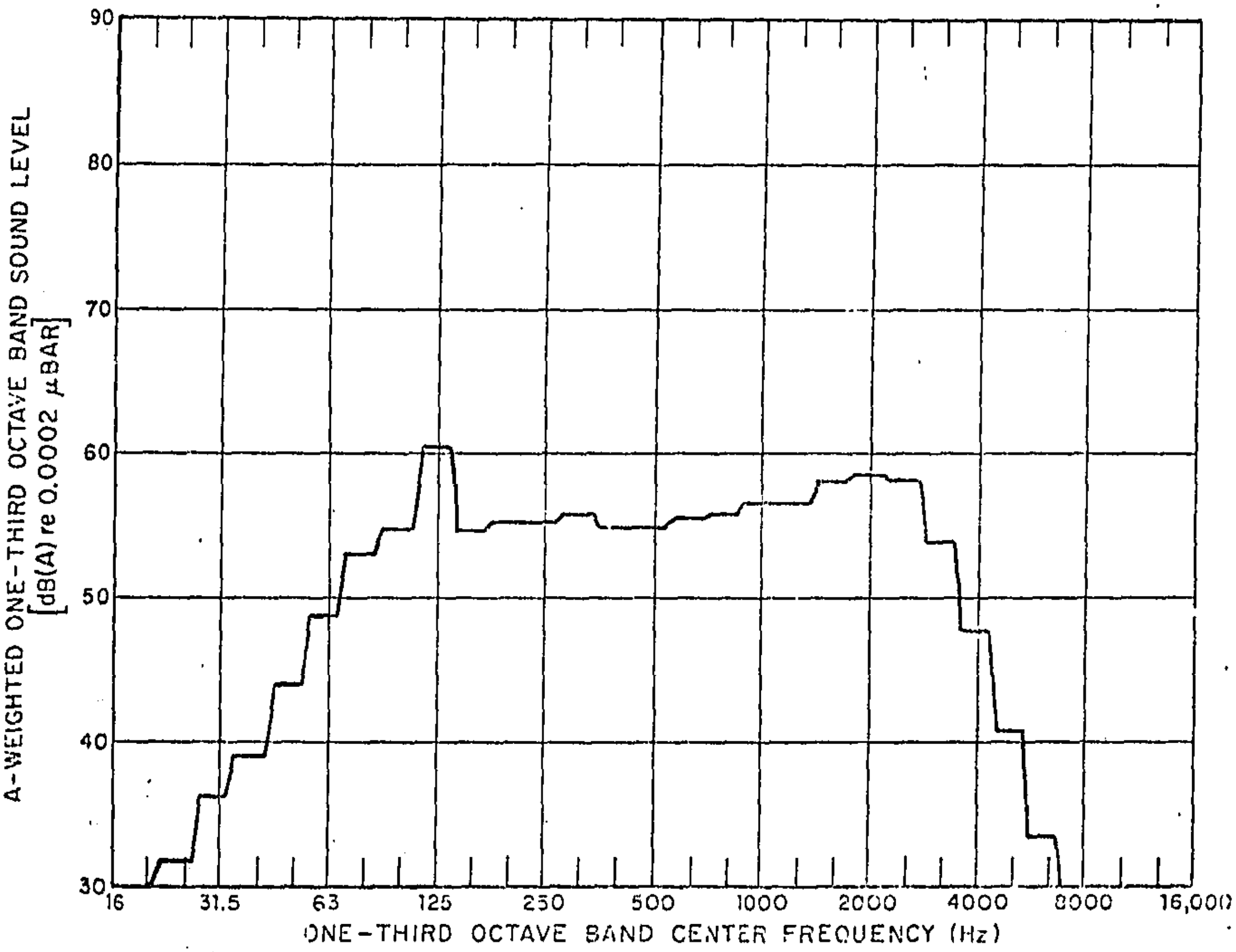

FIG. B.1.15. FREQUENCY ANALYSIS OF LATE PORTION (REGION 4) OF TRAIN NO. 6 NOISE AT 300 FT

(a) Looking North, Toward Tracks, from Near Field Measurement Point

(b) Looking South, Toward Far Field Measurement Point, from Near Field Measurement Point

FIG. B.2.1. PHOTOGRAPHS OF THE ELK RIVER NEAR FIELD MEASUREMENT POINT

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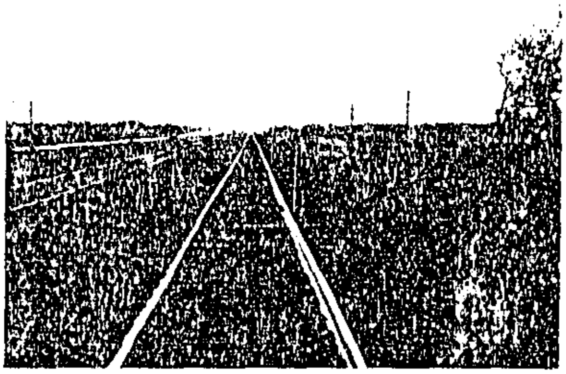
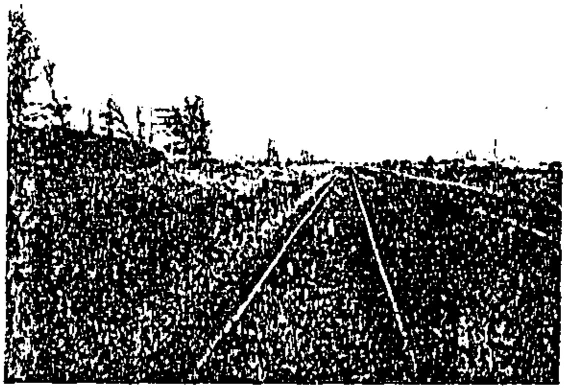


(c) Looking West from a Point just North of the Near Field Measurement Point



(d) Looking East from a Point just North of the Near Field Measurement Point

FIG. B.2.1. (CONT.)

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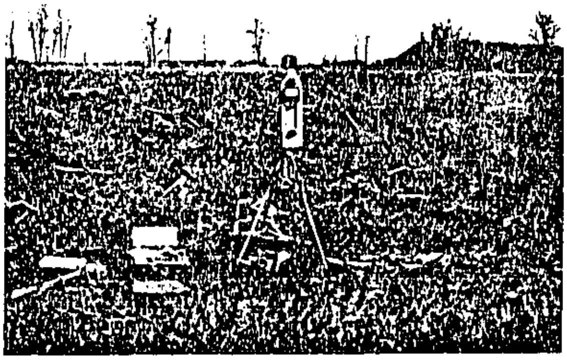
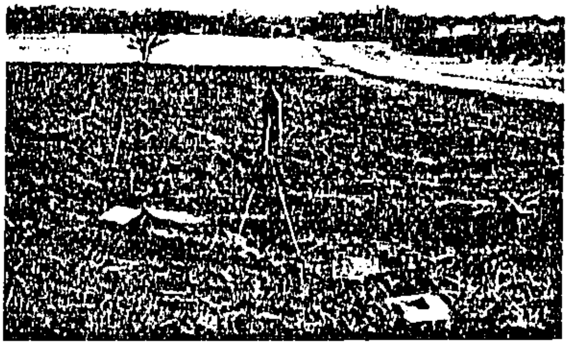


(a) Looking North, Toward Tracks, from Far Field Measurement Point



(b) Looking South, away from Tracks, from Far Field Measurement Point

FIG. B.2.2. PHOTOGRAPHS OF THE ELK RIVER FAR FIELD MEASUREMENT POINT

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(c) Looking East from Far Field Measurement Point

FIG. B.2.2. (CONT.)

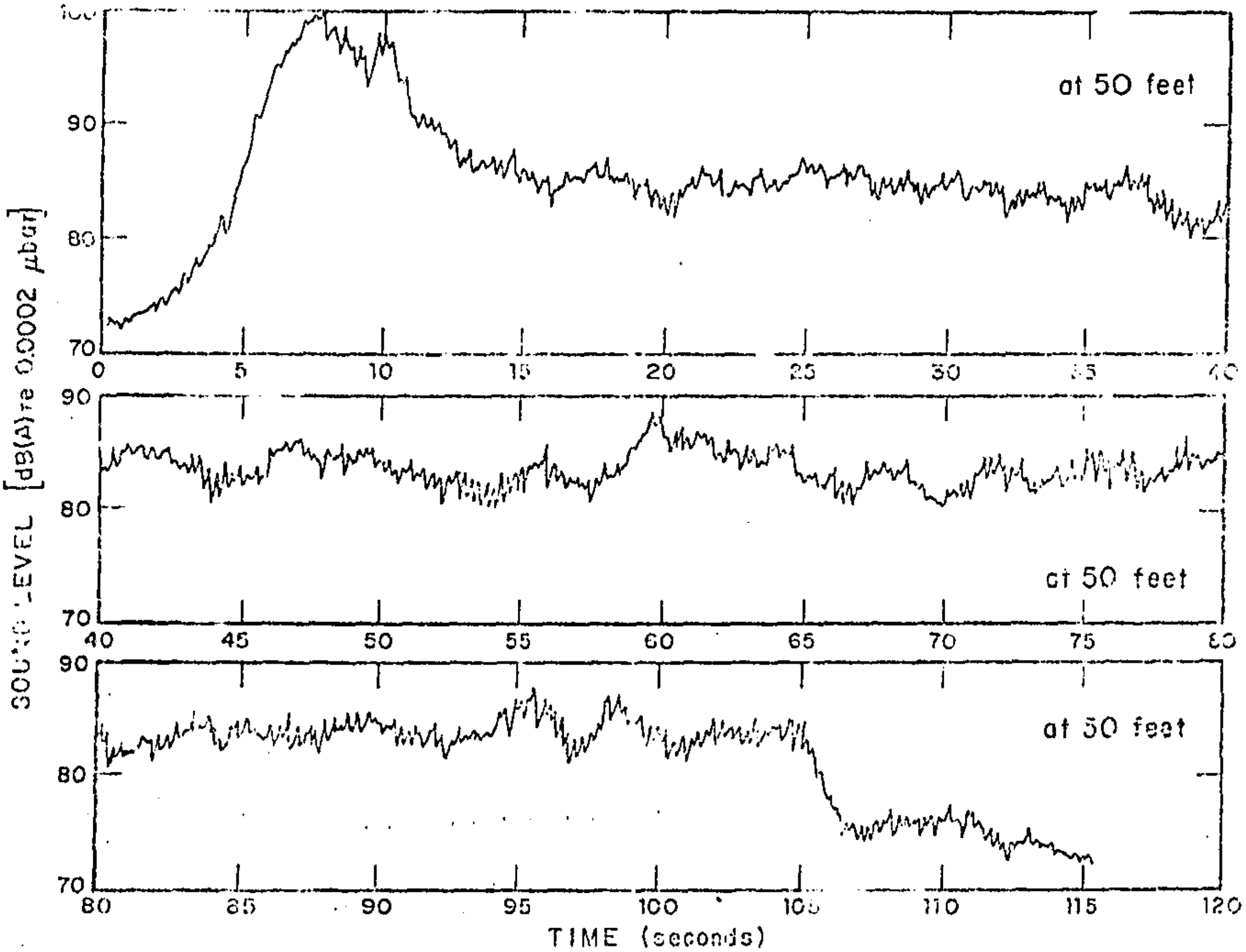
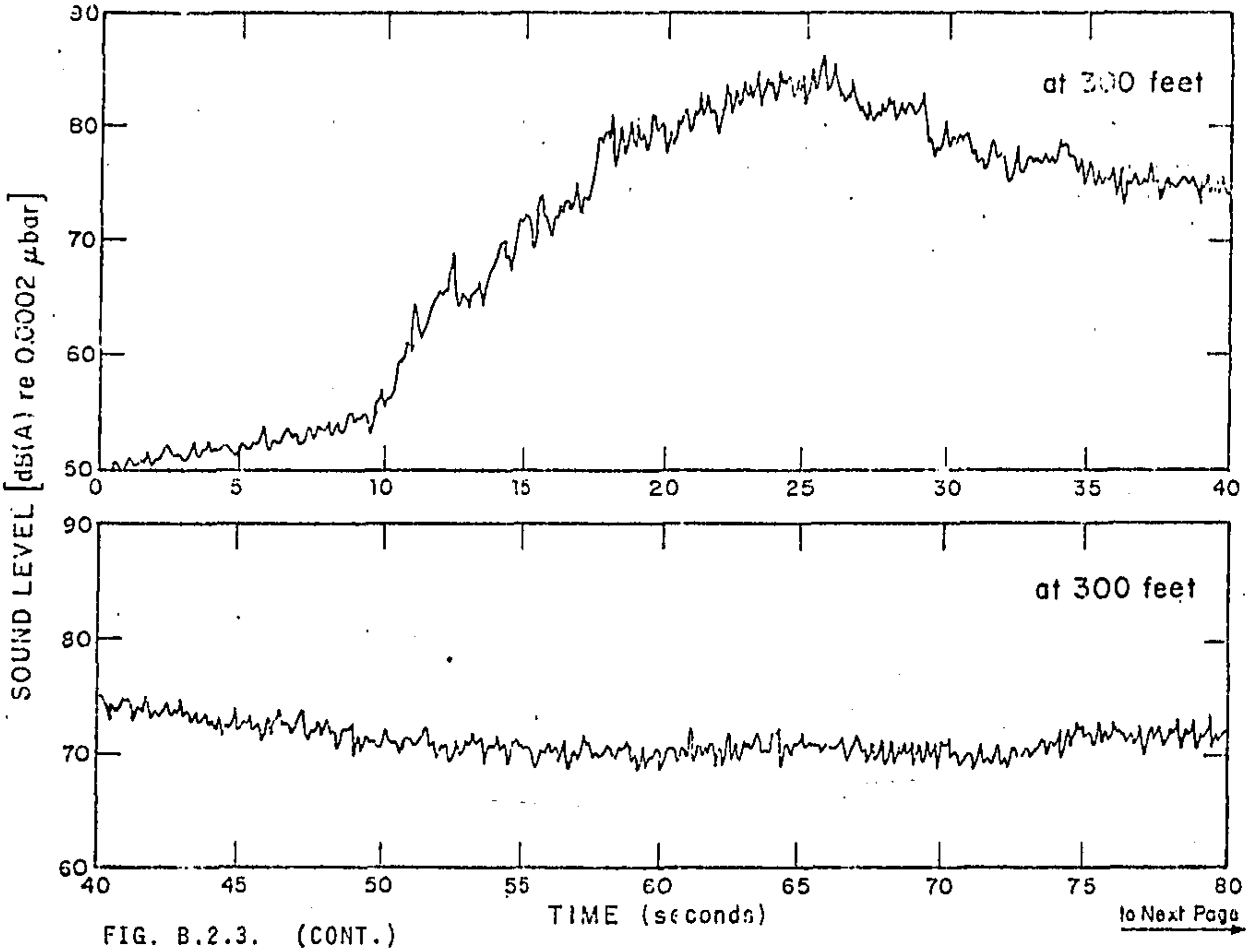


FIG. B.2.3. TRAIN NO. 9, FREIGHT, 10,500 hp (2 EMD SD-45's AND 1 EMD U33) 40 LOADED CARS, 80 MTS (5977 TONS) FLAT GRADE AT 40 mph (THROTTLE 8)



to Next Page →

FIG. B.2.3. (CONT.)

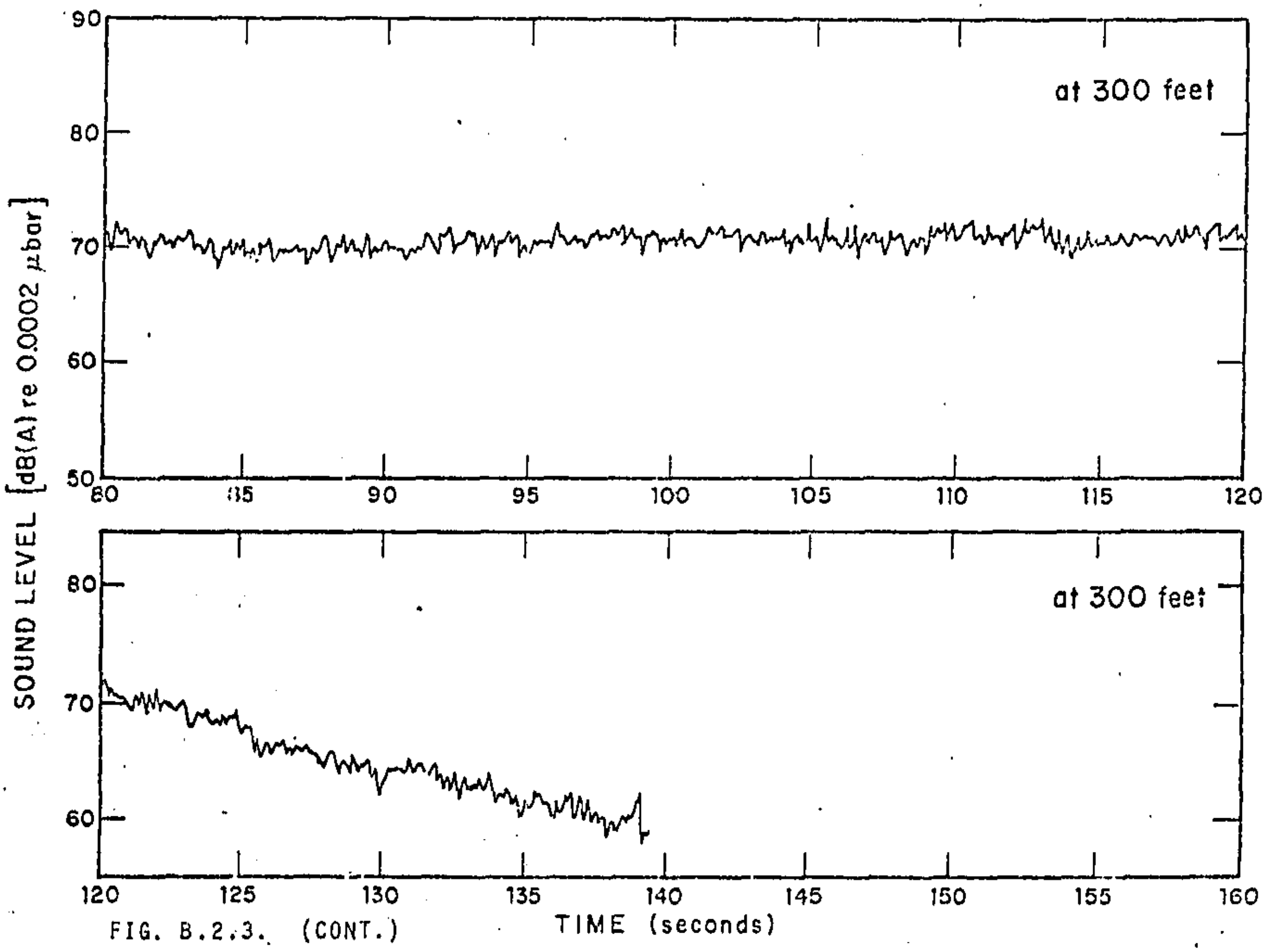

SOUND LEVEL [dB(A) re 0.0002 μbar]
90
80
70
60
50
at 300 feet
80
85
90
95
100
105
110
115
120
80
70
60
at 300 feet
120
125
130
135
140
145
150
155
160
TIME (seconds)

FIG. B.2.3. (CONT.)

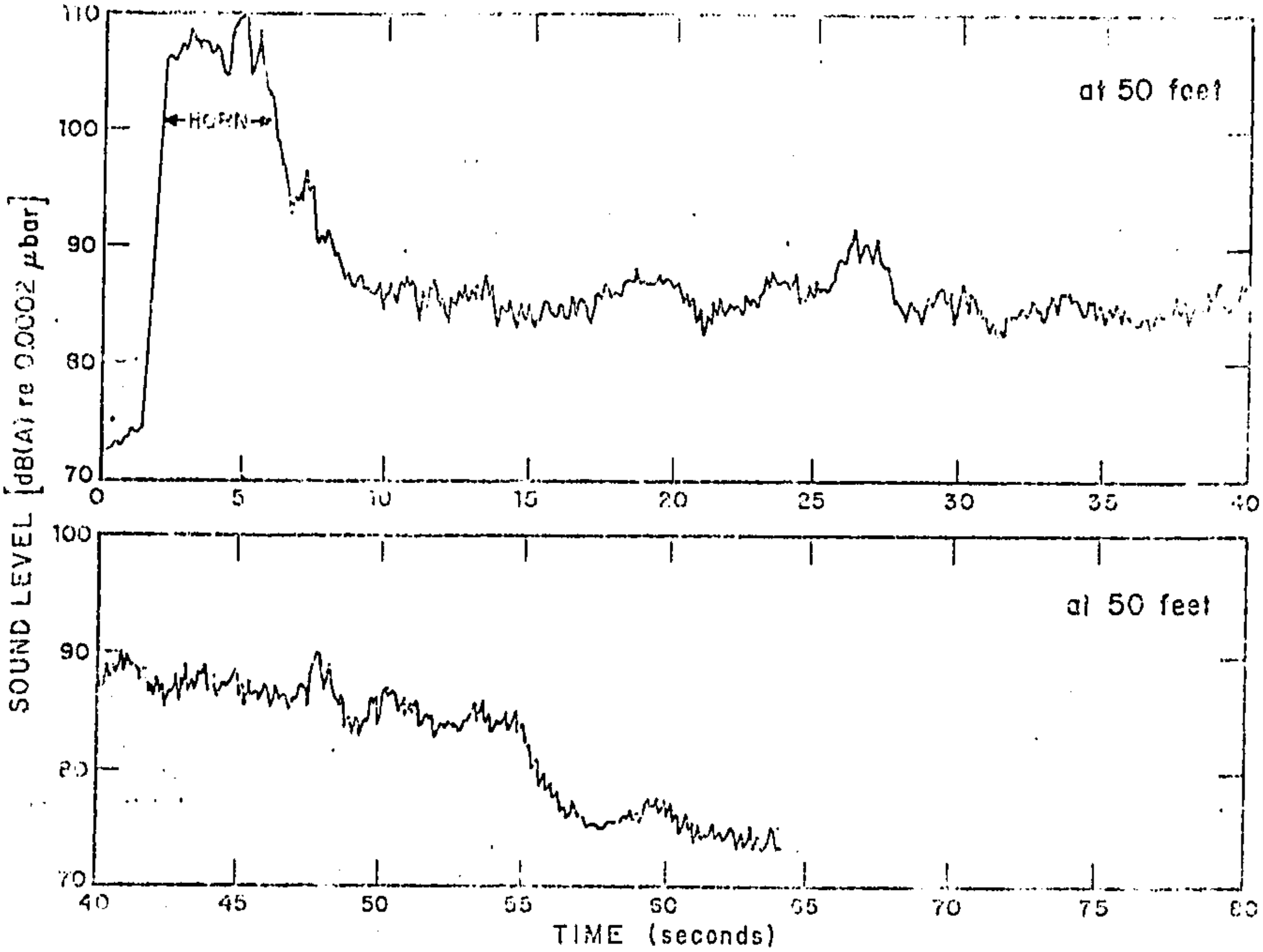


FIG. B.2.4. TRAIN NO. 10, FREIGHT, 6000 hp (2 EMD SD-40's), 70 CARS (2704 TONS) FLAT GRADE AT 53 mph (THROTTLE 8)

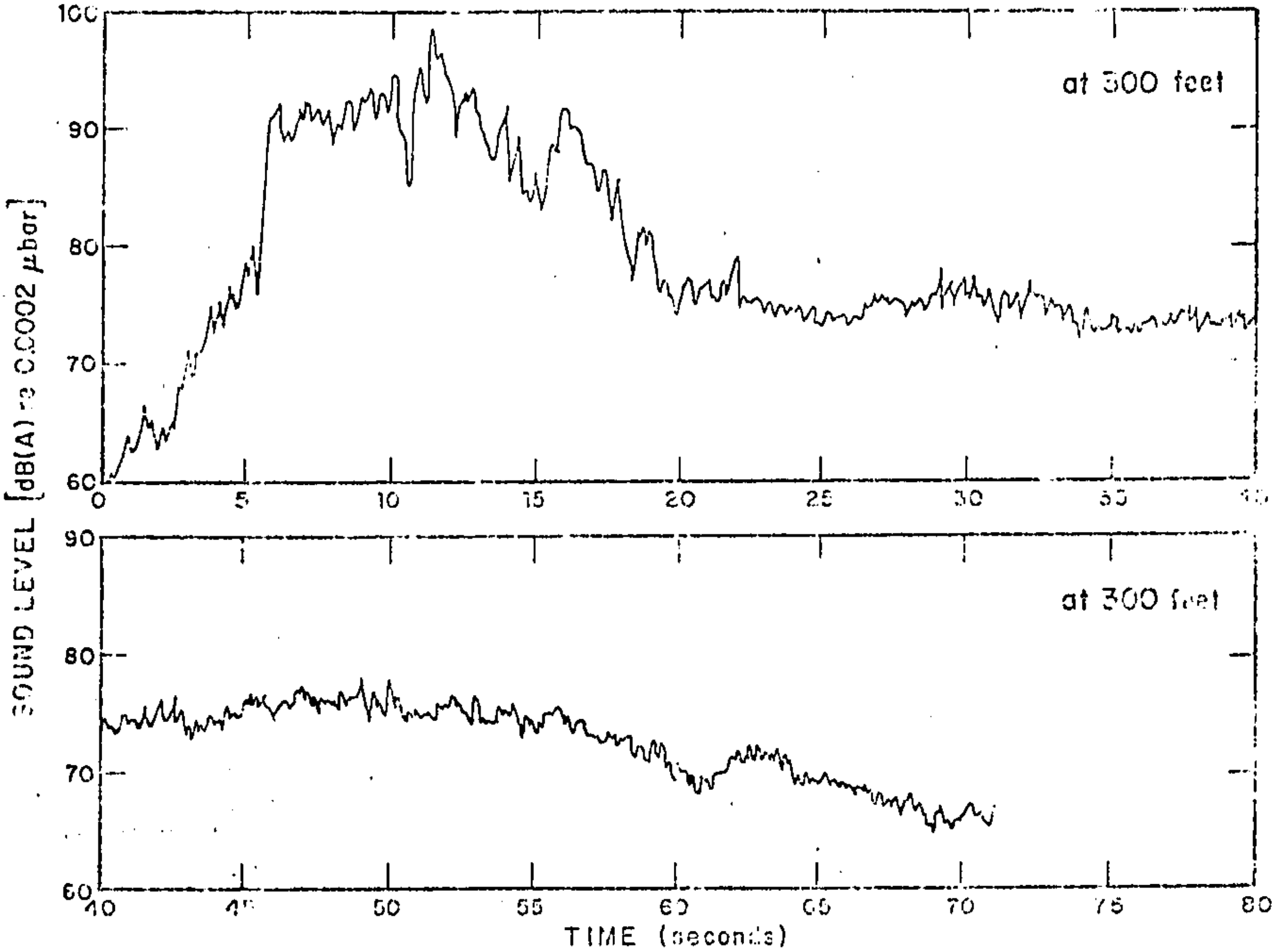

at 300 feet
at 300 feet
SOUND LEVEL [dB(A) re 0.0002 μbar]
100
90
80
70
60
0
5
10
15
20
25
30
35
40
90
80
70
60
40
45
50
55
60
65
70
75
80
TIME (seconds)

FIG. B.2.4. (CONT.)

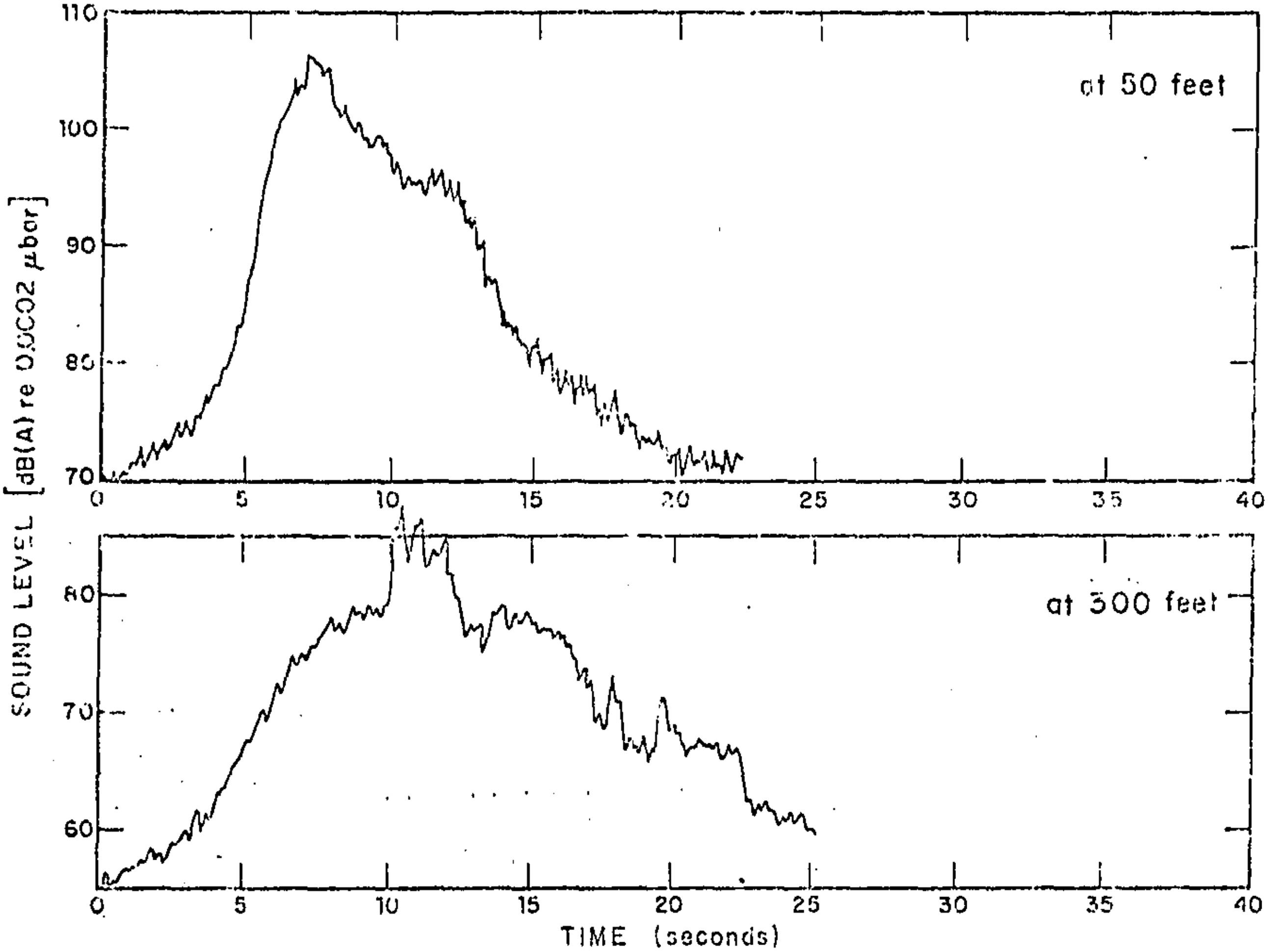


FIG. B.2.5. TRAIN NO. 11, AMTRACK PASSENGER, 4500 hp (3 EMD P-7 31-7's), 8 CARS FLAT GRADE AT 70 mph

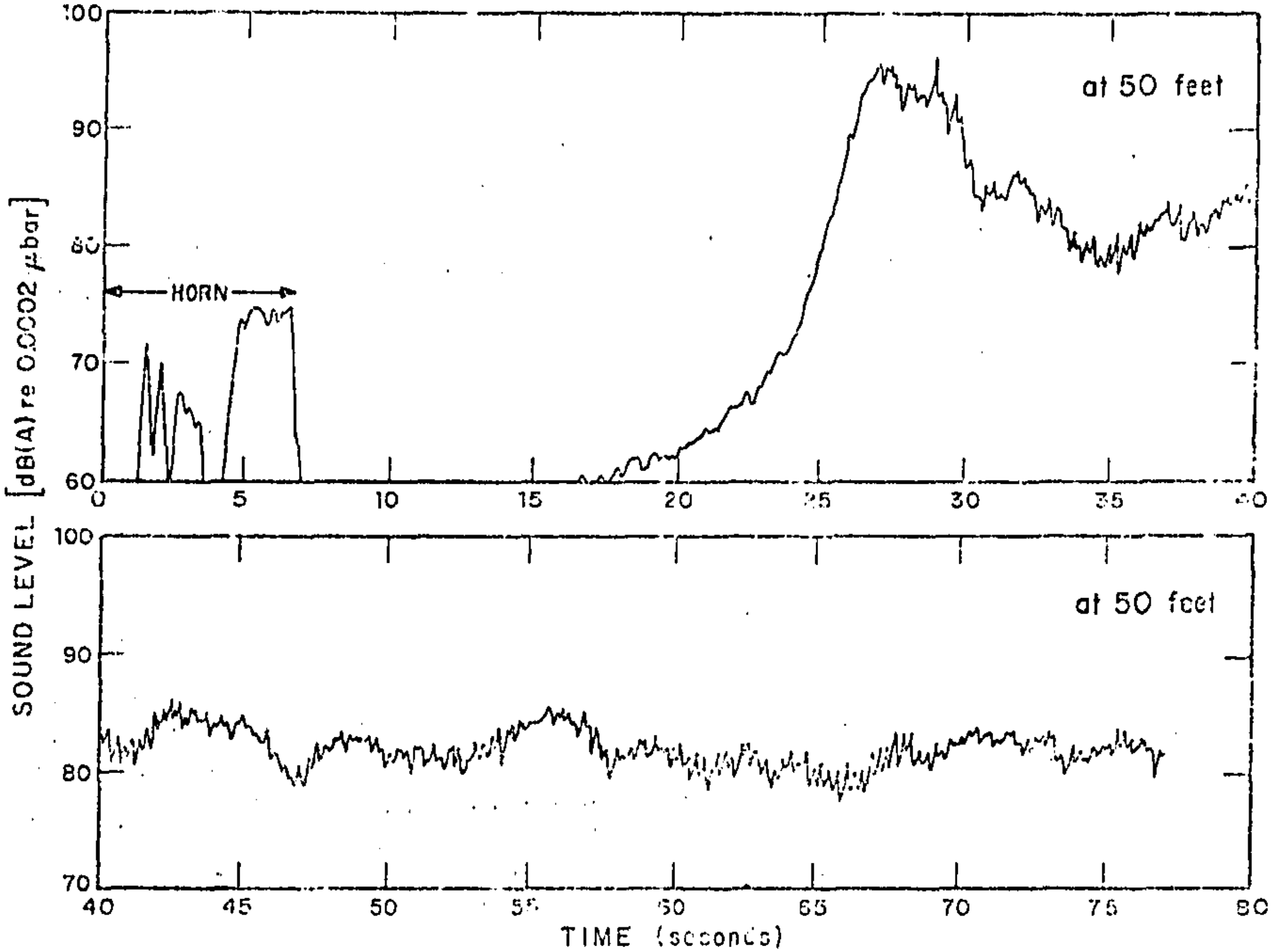


FIG. B.2.6. TRAIN NO. 12, FREIGHT, 6600 hp (EMD 1 SD 40, EMD 1 SD 45) 8 LOADED CARS, 107 EMPTIES (3758 TONS) FLAT GRADE AT 47 mph (THROTTLE 8)

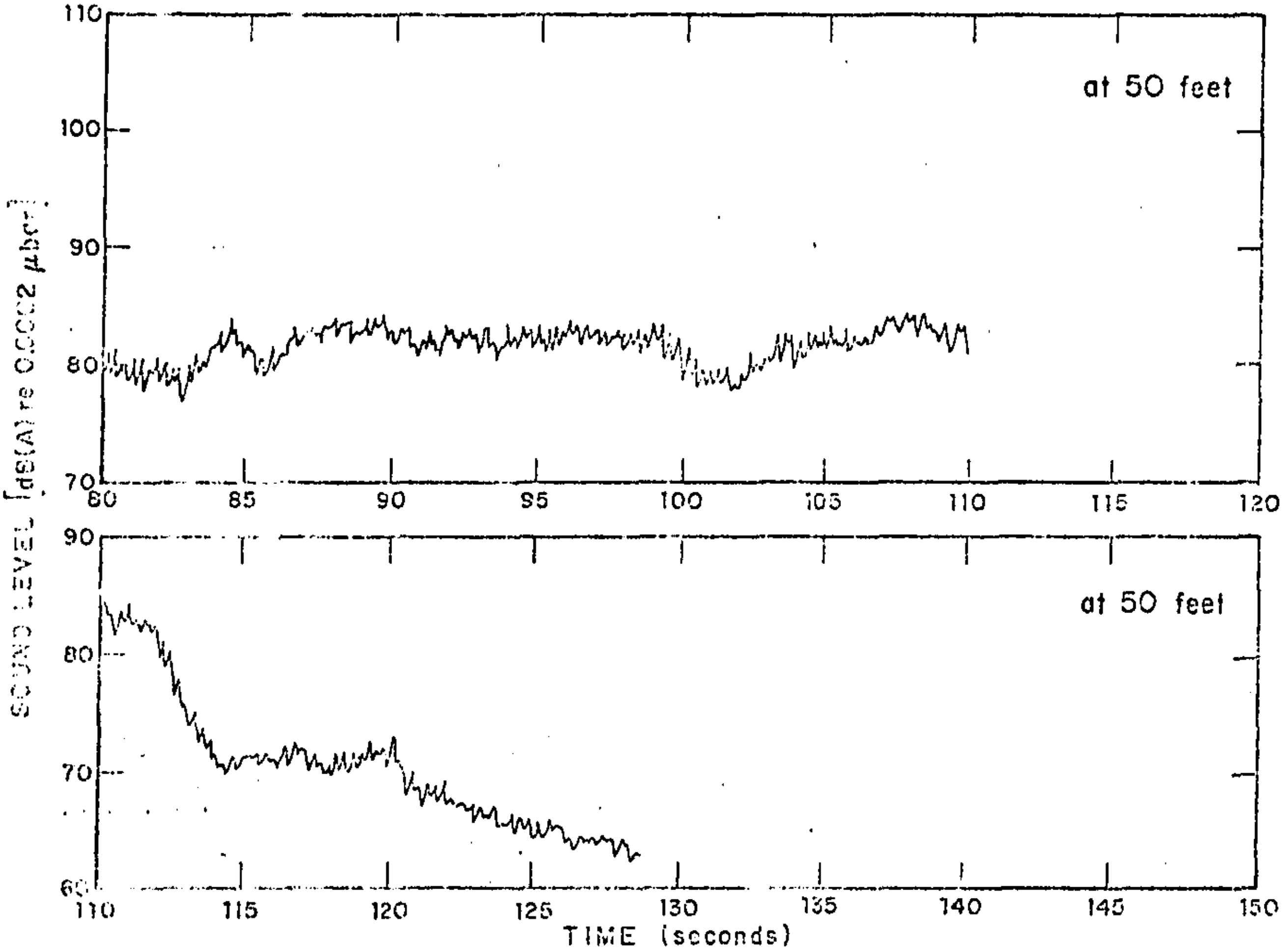

110
100
90
80
70
at 50 feet
80
85
90
95
100
105
110
115
120
90
80
70
60
at 50 feet
110
115
120
125
130
135
140
145
150
TIME (seconds)
SOUND LEVEL [dB(A) re 0.0002 μbar]

FIG. B.2.6. (CONT.)

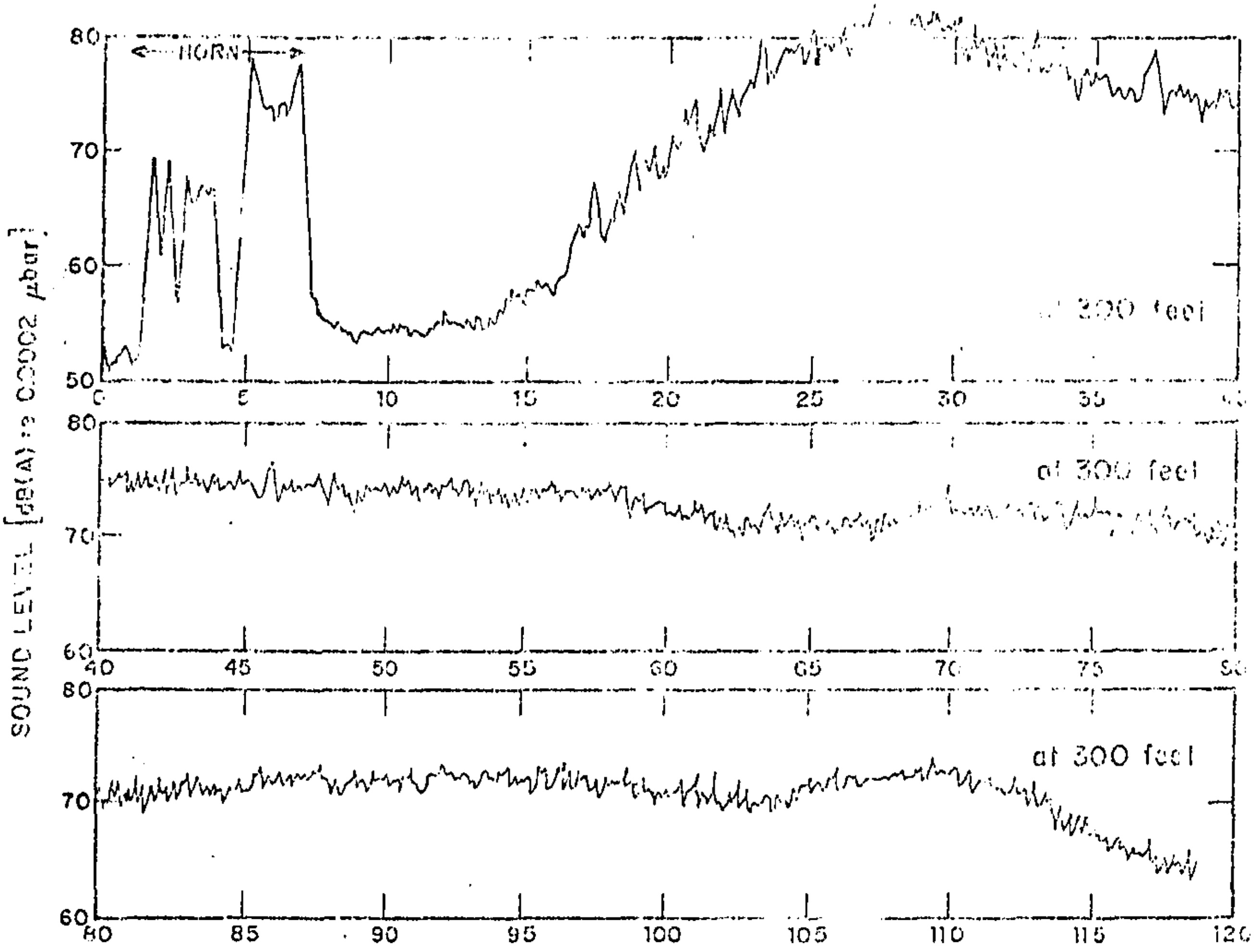

SOUND LEVEL [dB(A) re 0.0002 μbar]
HORN
at 300 feet
at 300 feet
at 300 feet
80
70
60
50
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
TIME (seconds)

FIG. B.2.6. (CONT.)

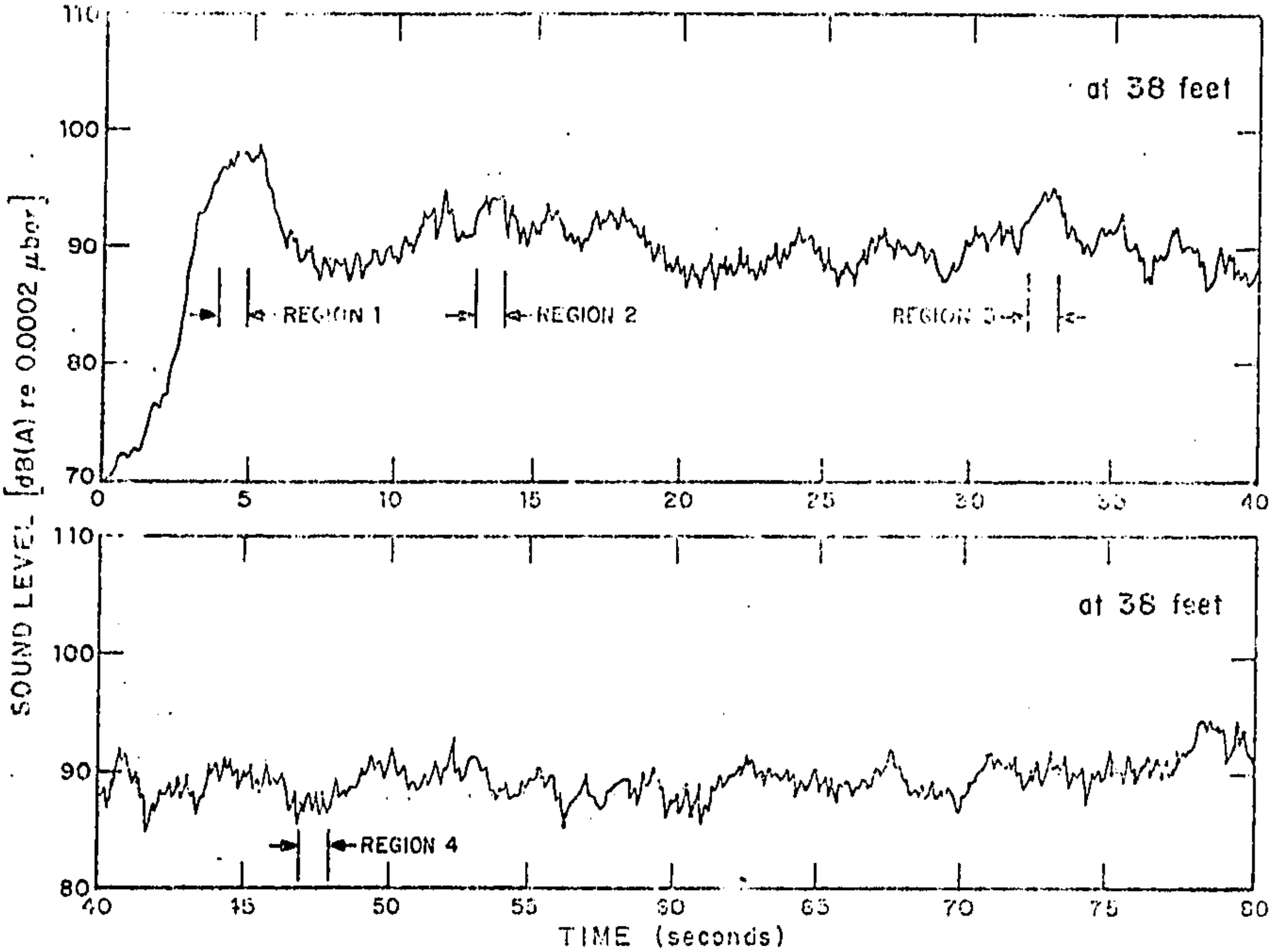


FIG. B.2.7. TRAIN NO. 13, FREIGHT, 7750 hp (2 EMD GP-40's AND 1 EMD GP-9) 56 LOADED CARS, 64 EMPTIES (6641 TONS) FLAT GRADE AT 58 mph (THROTTLE 8)

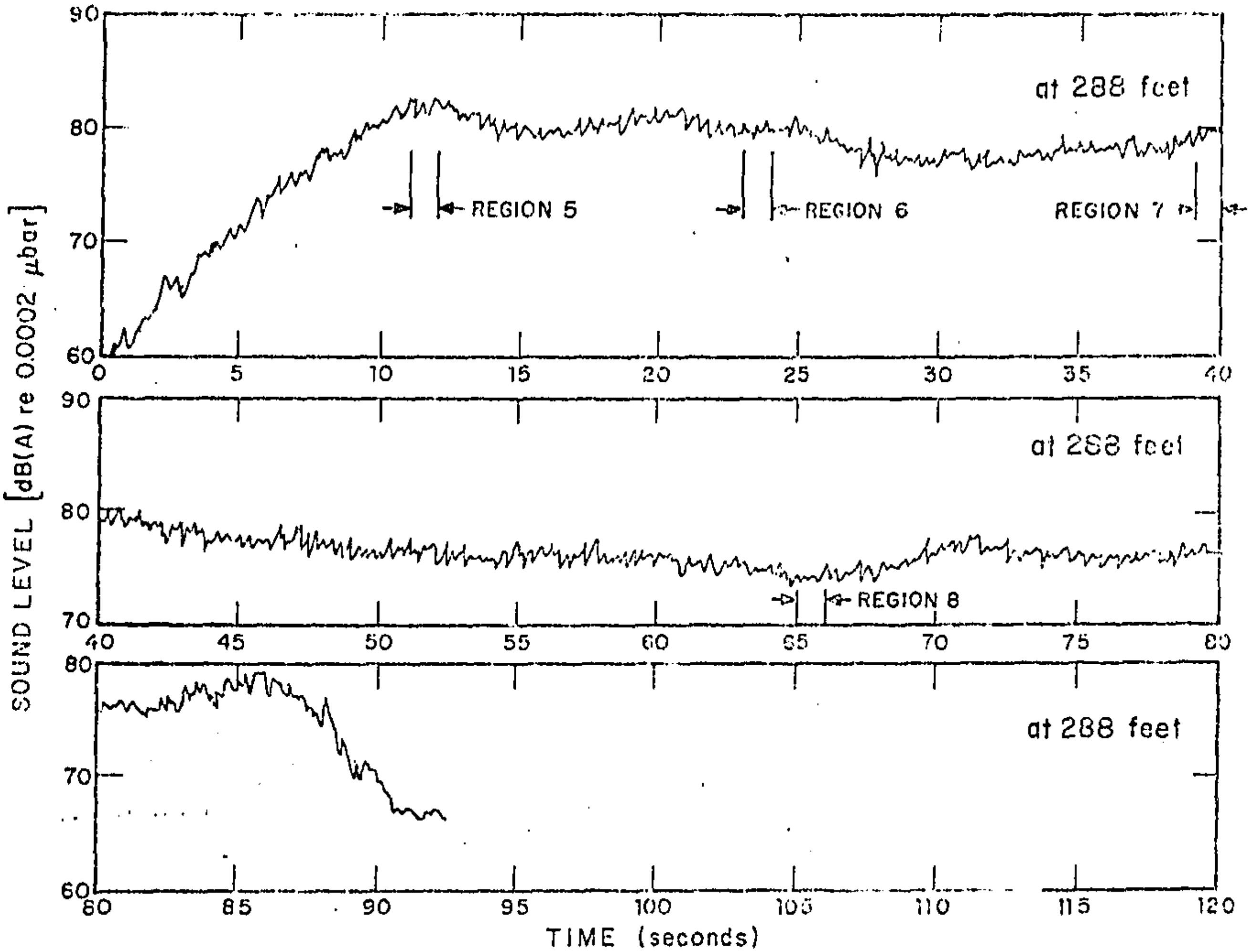

SOUND LEVEL [dB(A) re 0.0002 μbar]
at 288 feet
REGION 5
REGION 6
REGION 7
REGION 8
90
80
70
60
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
TIME (seconds)

FIG. B.2.7. (CONT.)

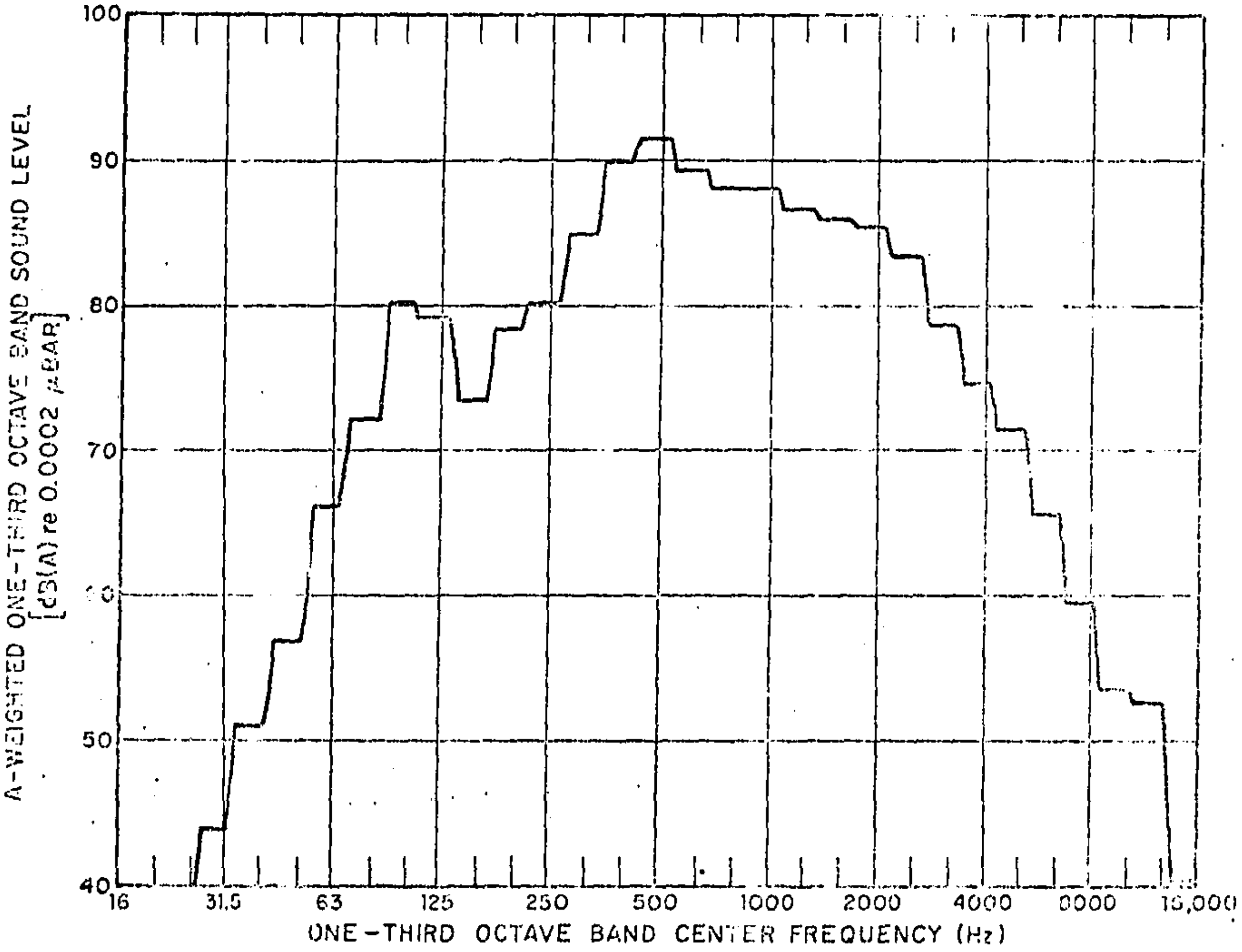


FIG. B.2.8. FREQUENCY ANALYSIS OF EARY PORTION OF TRAIN NO. 13 NOISE AT 38 FT, REGION 1.

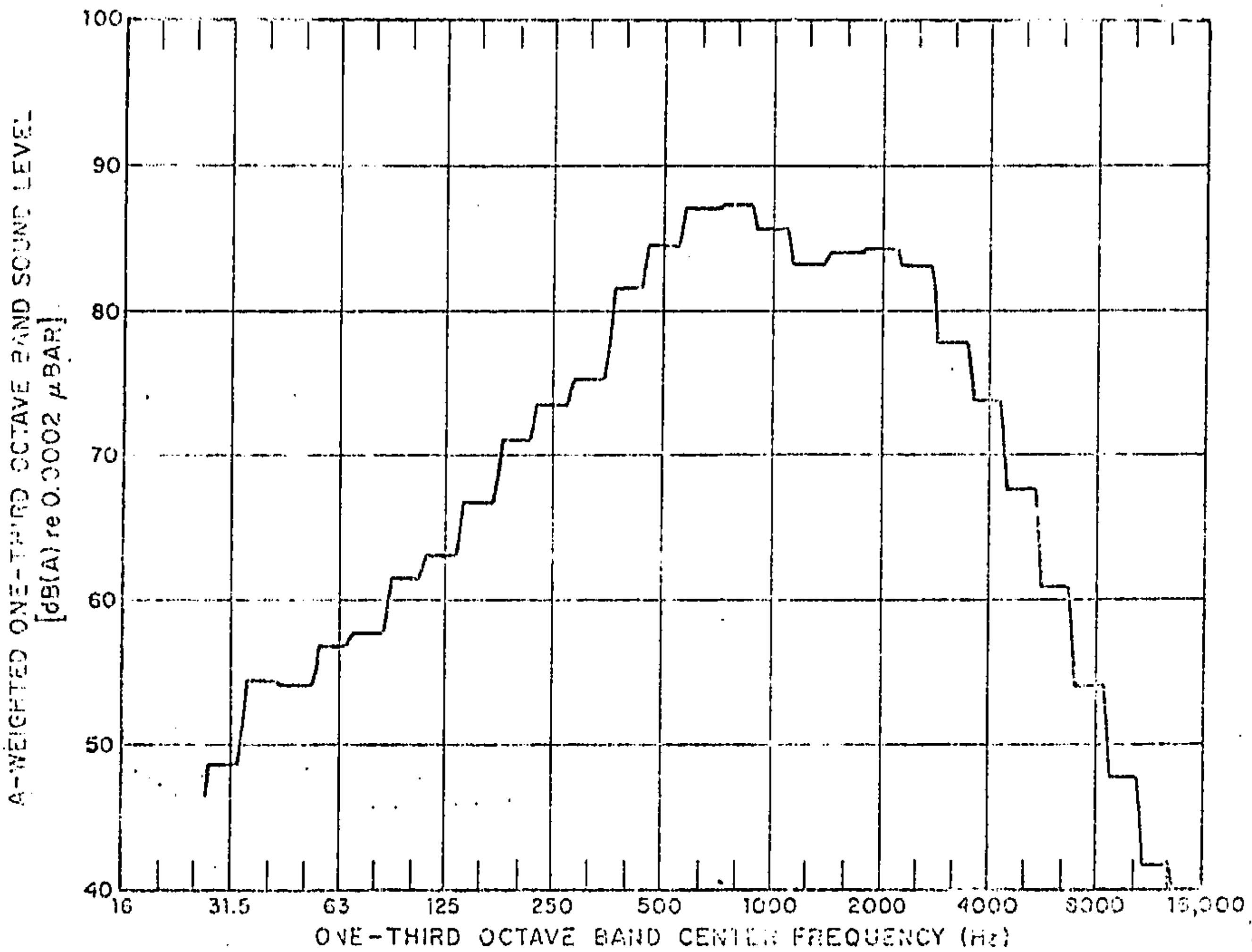


FIG. B.2.9(a) FREQUENCY ANALYSIS OF LATE PORTIONS OF TRAIN NO. 13 NOISE AT 38 FT, REGION 2

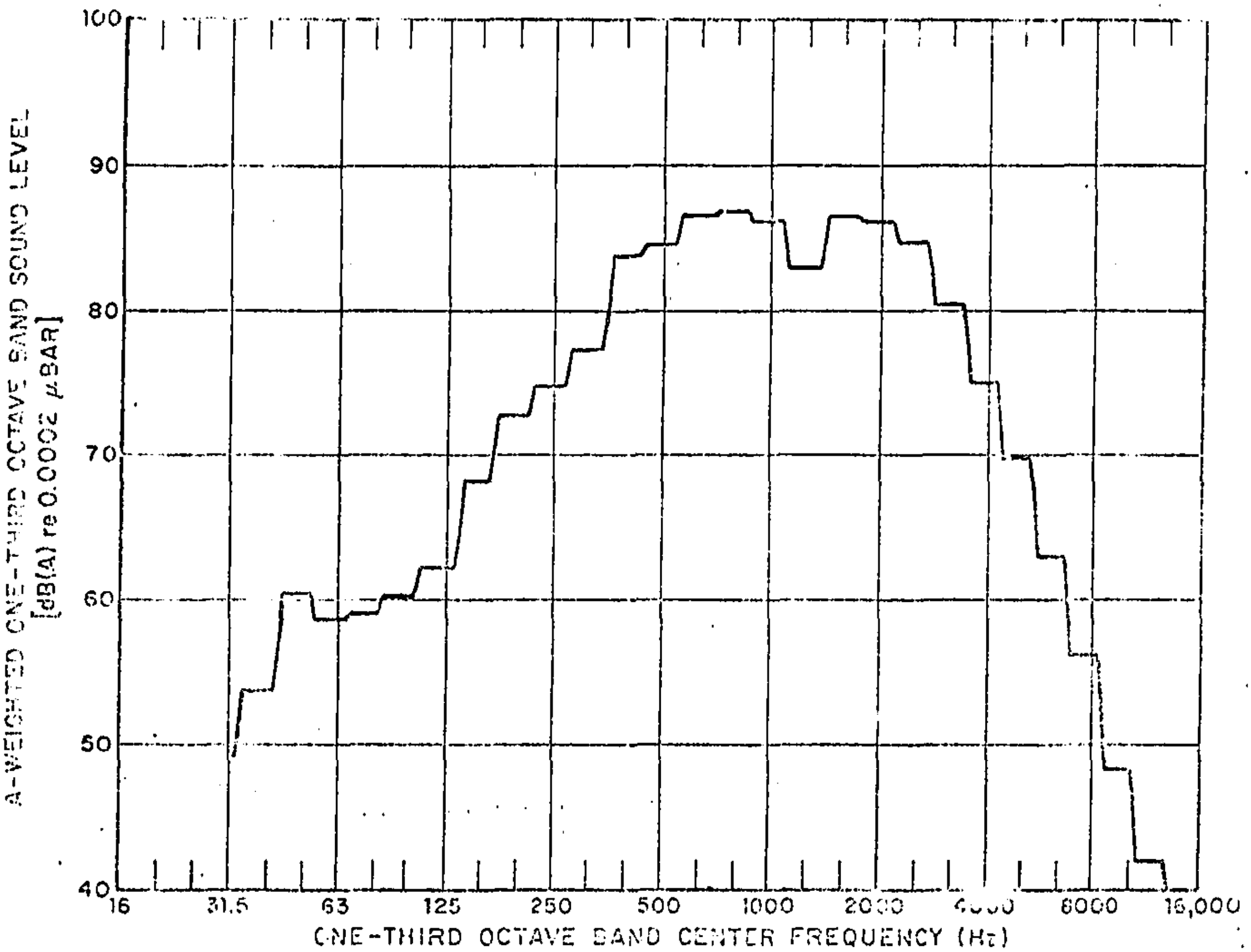


FIG. B.2.9(b) REGION 3

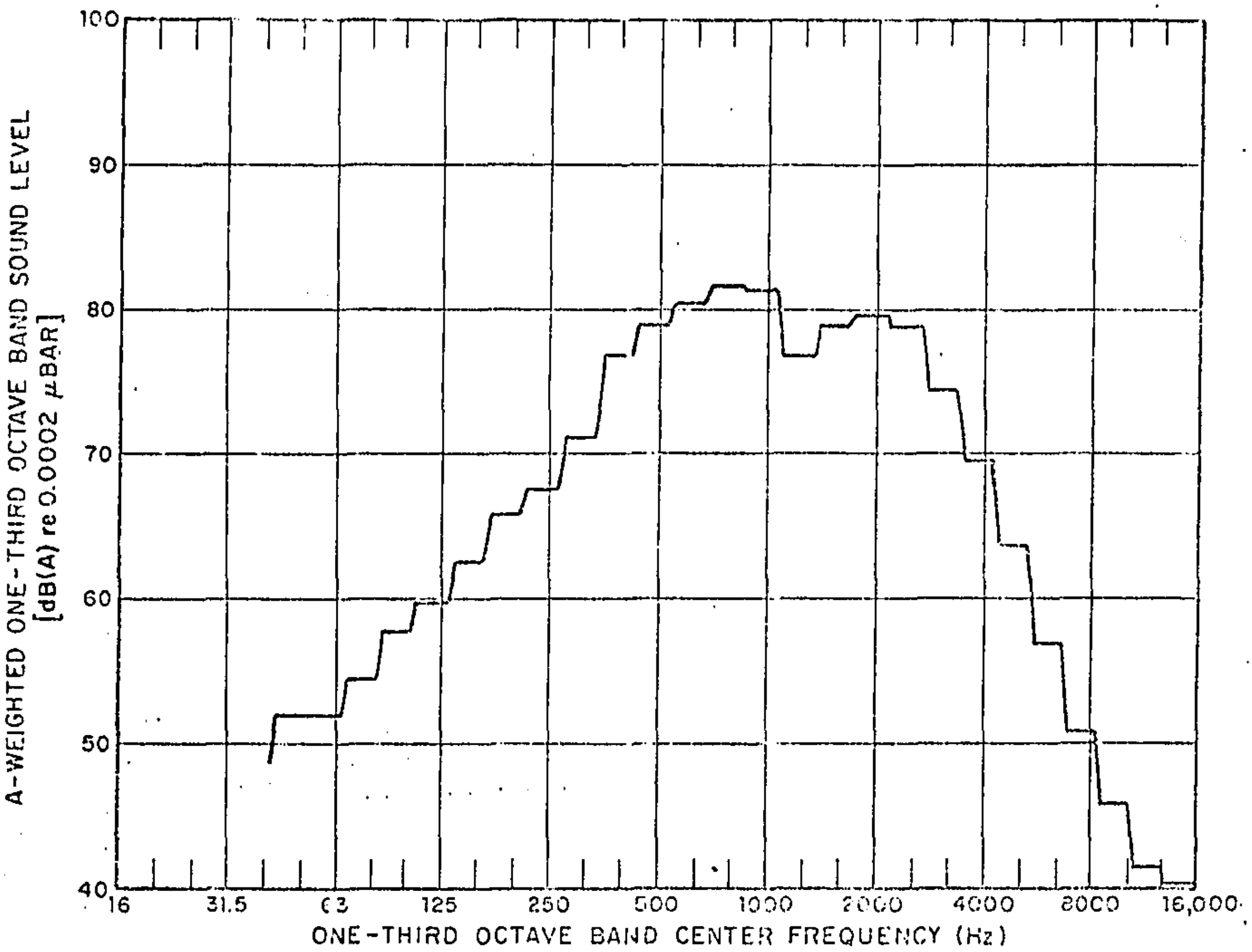


FIG. B.2.9(c) REGION 4

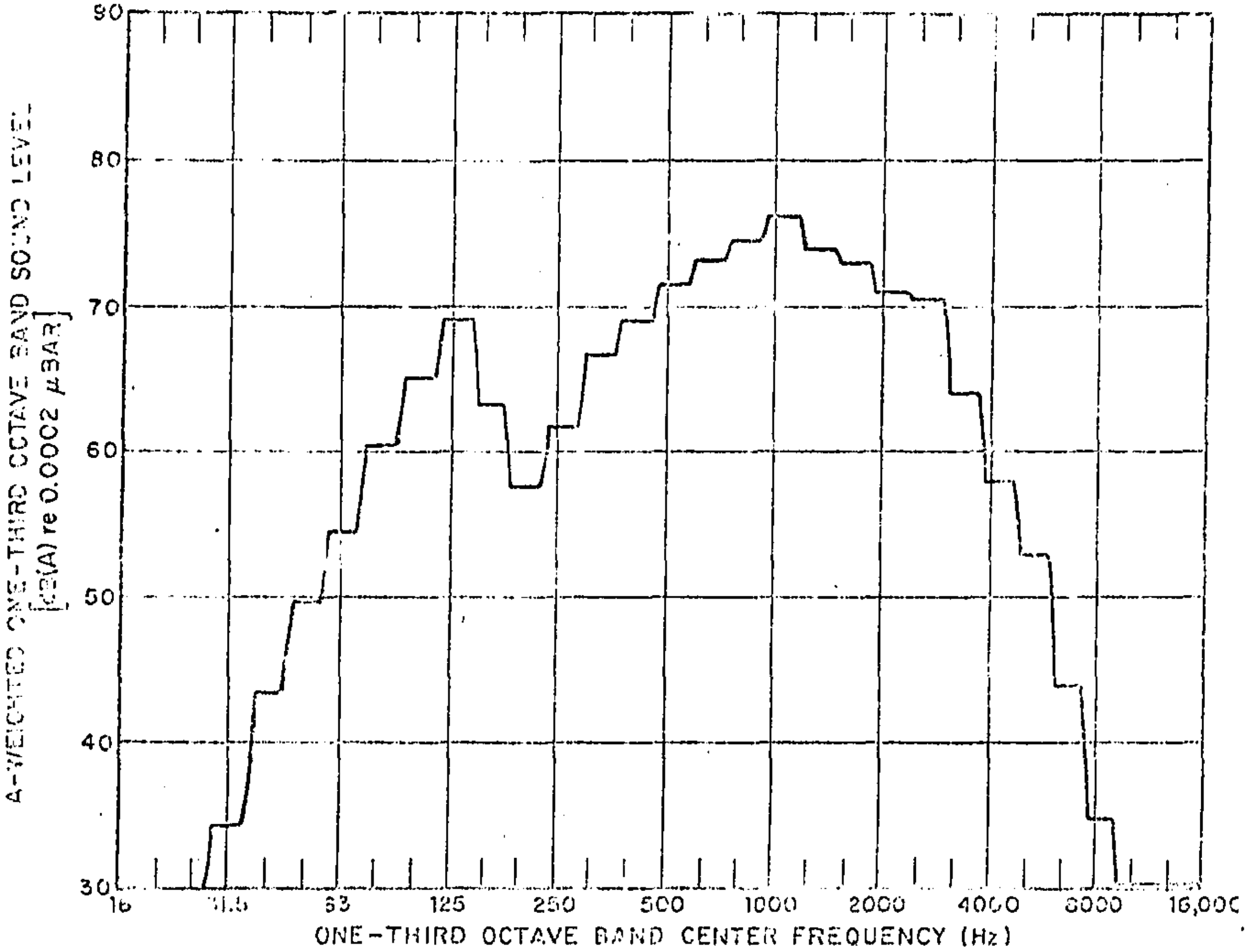


FIG. B.2.10. FREQUENCY ANALYSIS OF EARLY PORTION OF TRAIN NO. 13 NOISE AT 288 FT, REGION 5

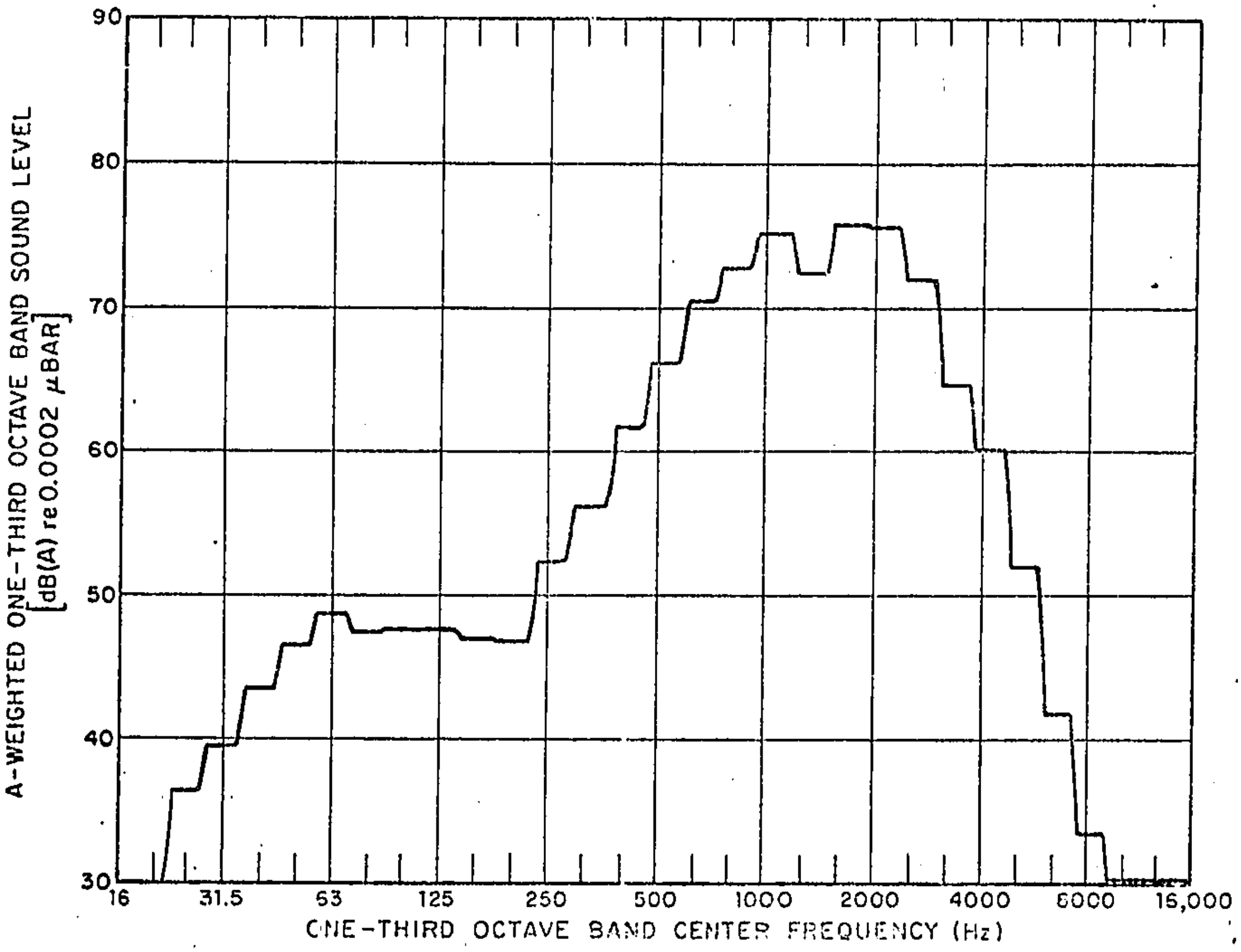


FIG. B.2.11(a) FREQUENCY ANALYSIS OF LATE PORTIONS OF TRAIN NO. 13 NOISE AT 288 FT, REGION 6

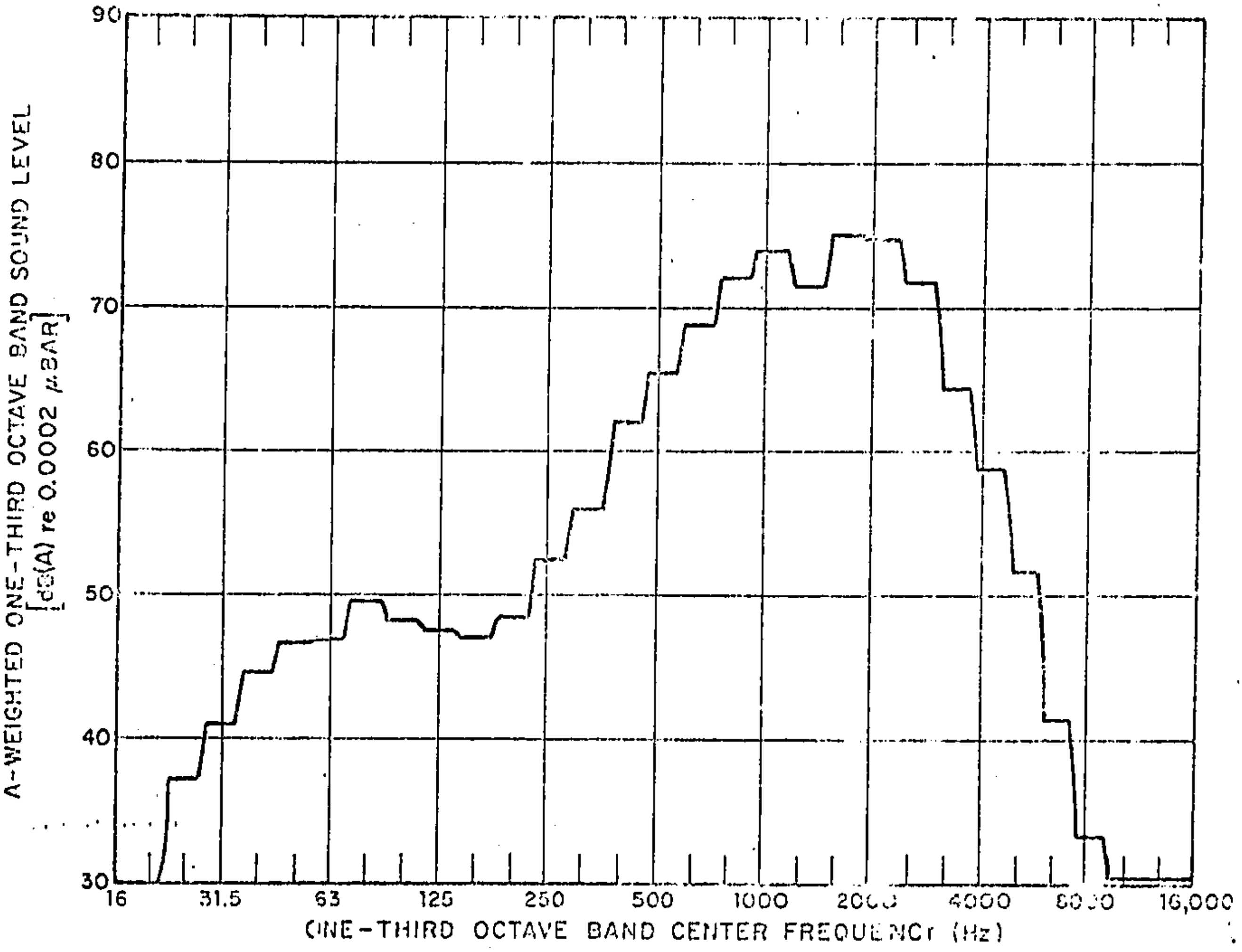


FIG. B.2.11(b) REGION 7

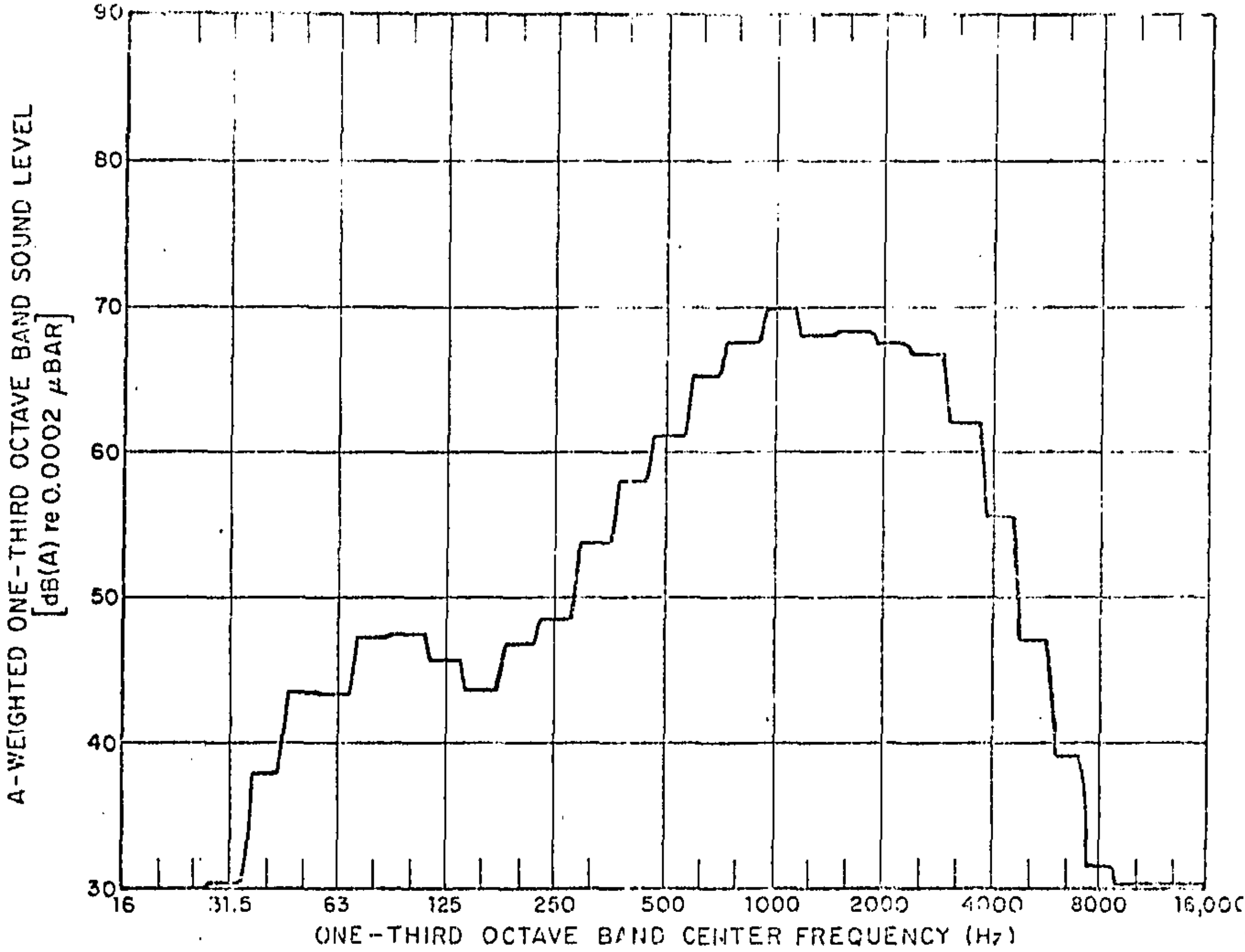


FIG. B.2.11(c). REGION 8

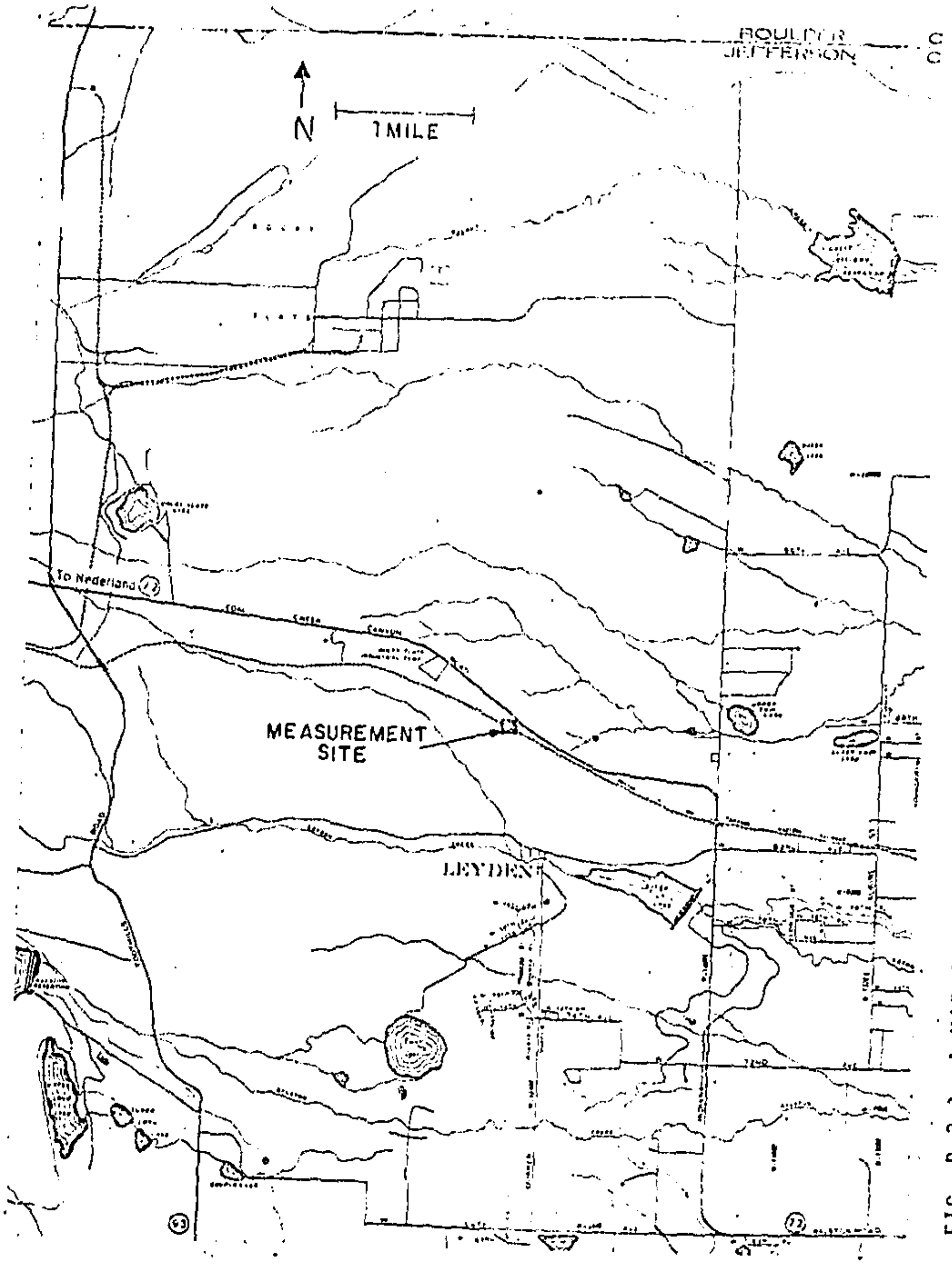


FIG. B.3.1 A MAP OF THE VICINITY OF THE LEYDEN GRADE

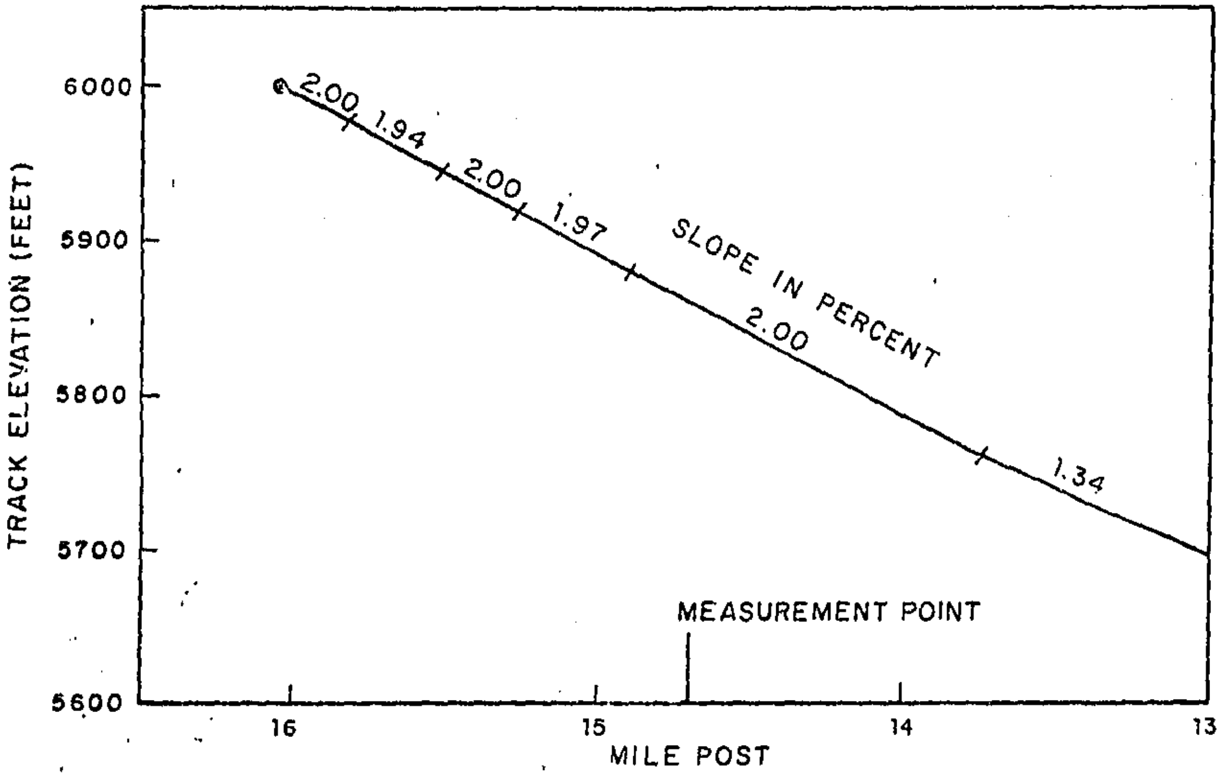
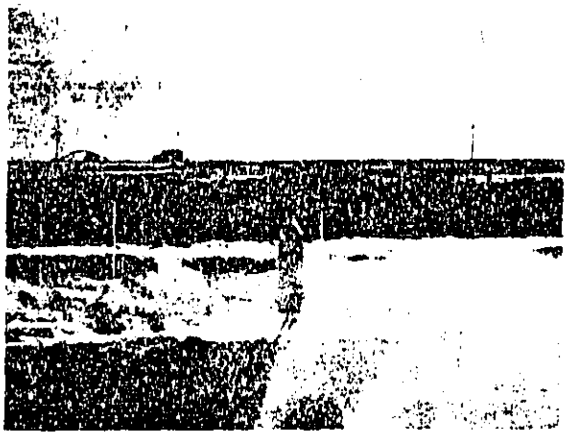
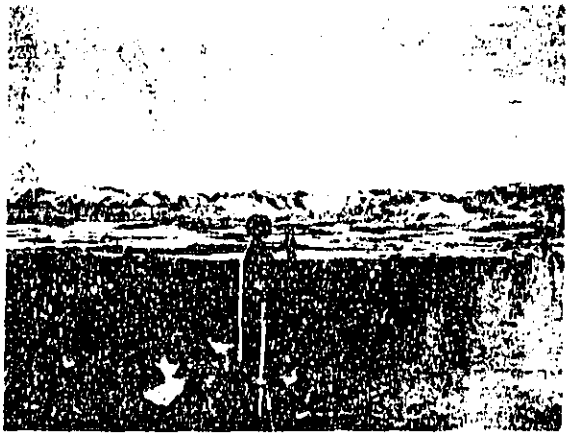


FIG. B.3.2. TRACK PROFILE AT AND NEAR THE LEYDEN GRADE



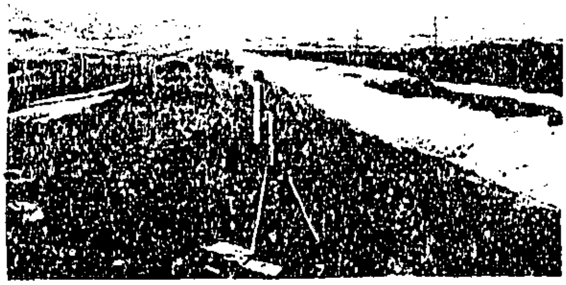
(a) Looking North Past the Near Field Measurement Point



(b) Looking South Past the Near Field Measurement Point

FIG. 8.3.3. PHOTOGRAPHS OF THE LEYDEN GRADE NEAR FIELD MEASUREMENT POINT

BLACK COPY



(c) Looking West Past the Near Field Measurement Point

FIG. B.3.3. (CONT.)

BLACK COPY

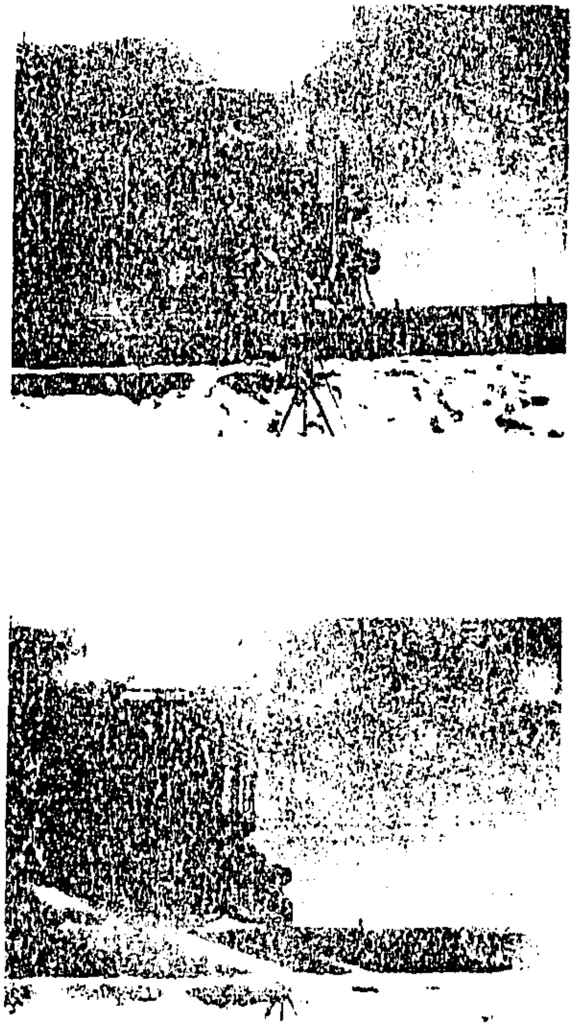


FIG. B.3.4. PHOTOGRAPHS OF TRAINS MOVING DOWNGRADE PAST THE LEYDEN GRADE NEAR FIELD MEASUREMENT POINT

BLACK COPY

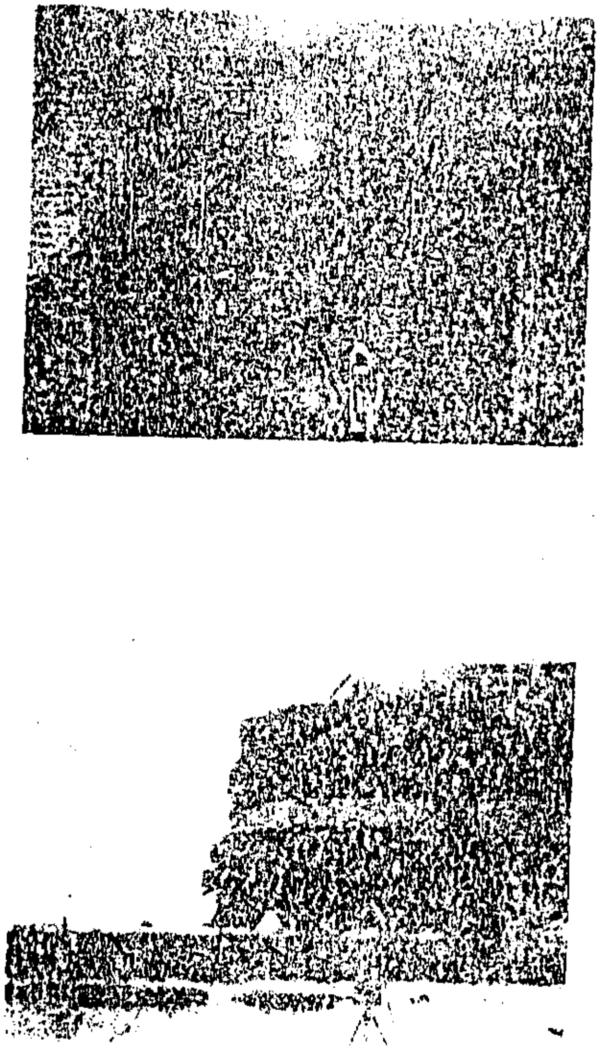
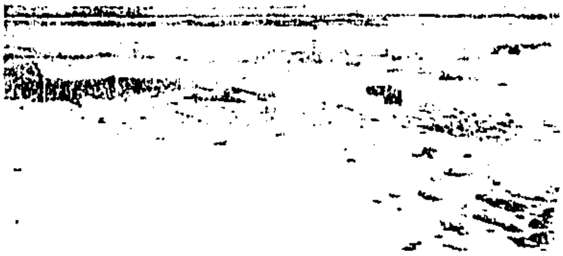


FIG. B.3.5. PHOTOGRAPHS OF TRAINS MOVING UPGRADE PAST THE LEYDEN GRADE NEAR FIELD MEASUREMENT POINT

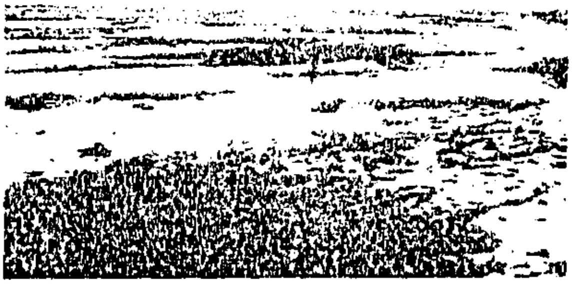
BLACK COPY



(a) Looking North (Toward Tracks) Past Far Field Measurement Point

(b) Looking South Past Far Field Measurement Point

FIG. B.3.6. PHOTOGRAPHS OF THE LEYDEN GRADE FAR FIELD MEASUREMENT POINT



(c) Looking East Past Far Field Measurement Point

(d) Looking West Past Far Field Measurement Point

FIG. B.3.6. (CONT.)

BLACK COPY

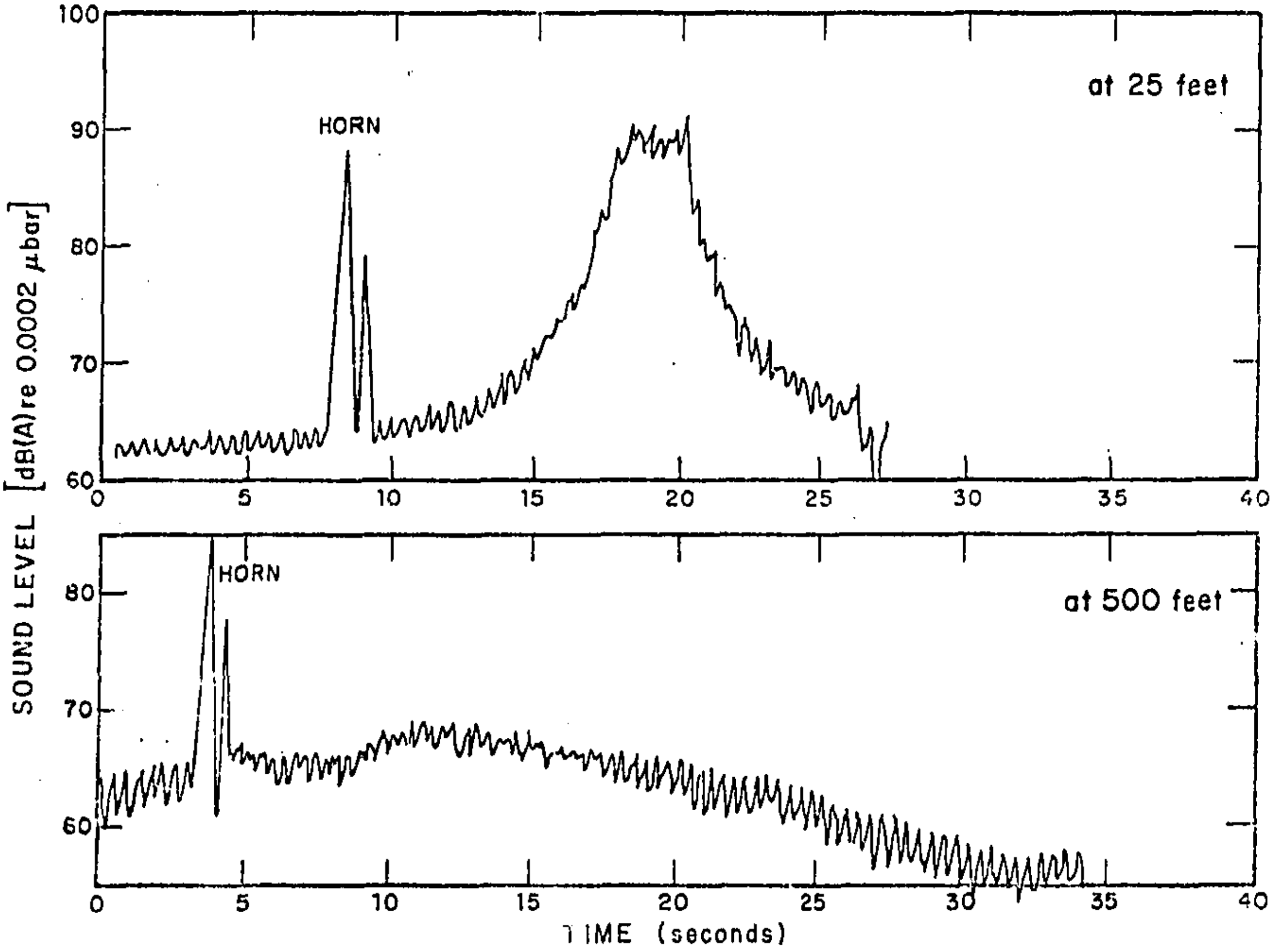


FIG. B.3.7. TRAIN NO. 1, TWO HELPER LOCOMOTIVES, 2250 hp AND 3000 hp, GOING DOWN A 2% GRADE AT 25 mph

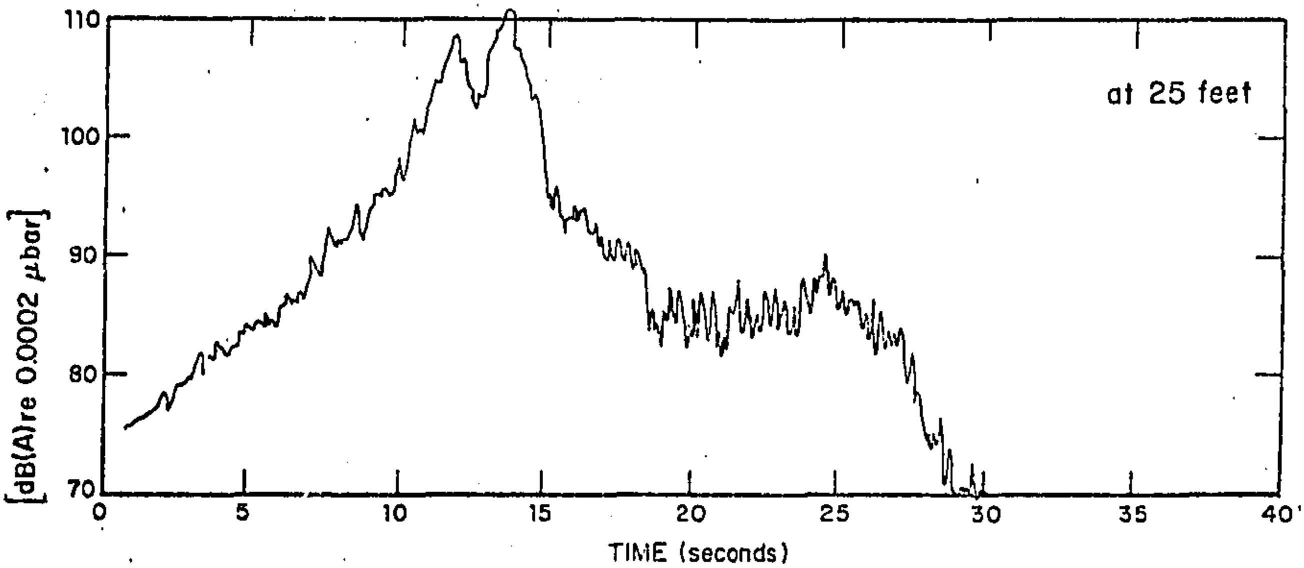


FIG. B.3.8. TRAIN NO. 2, PASSENGER, 3000 hp (2 EMD F-7's), 6 CARS, CLIMBING A 2% GRADE AT 15 mph (SHIFTING THROTTLE POSITIONS, HAVING TROUBLE)

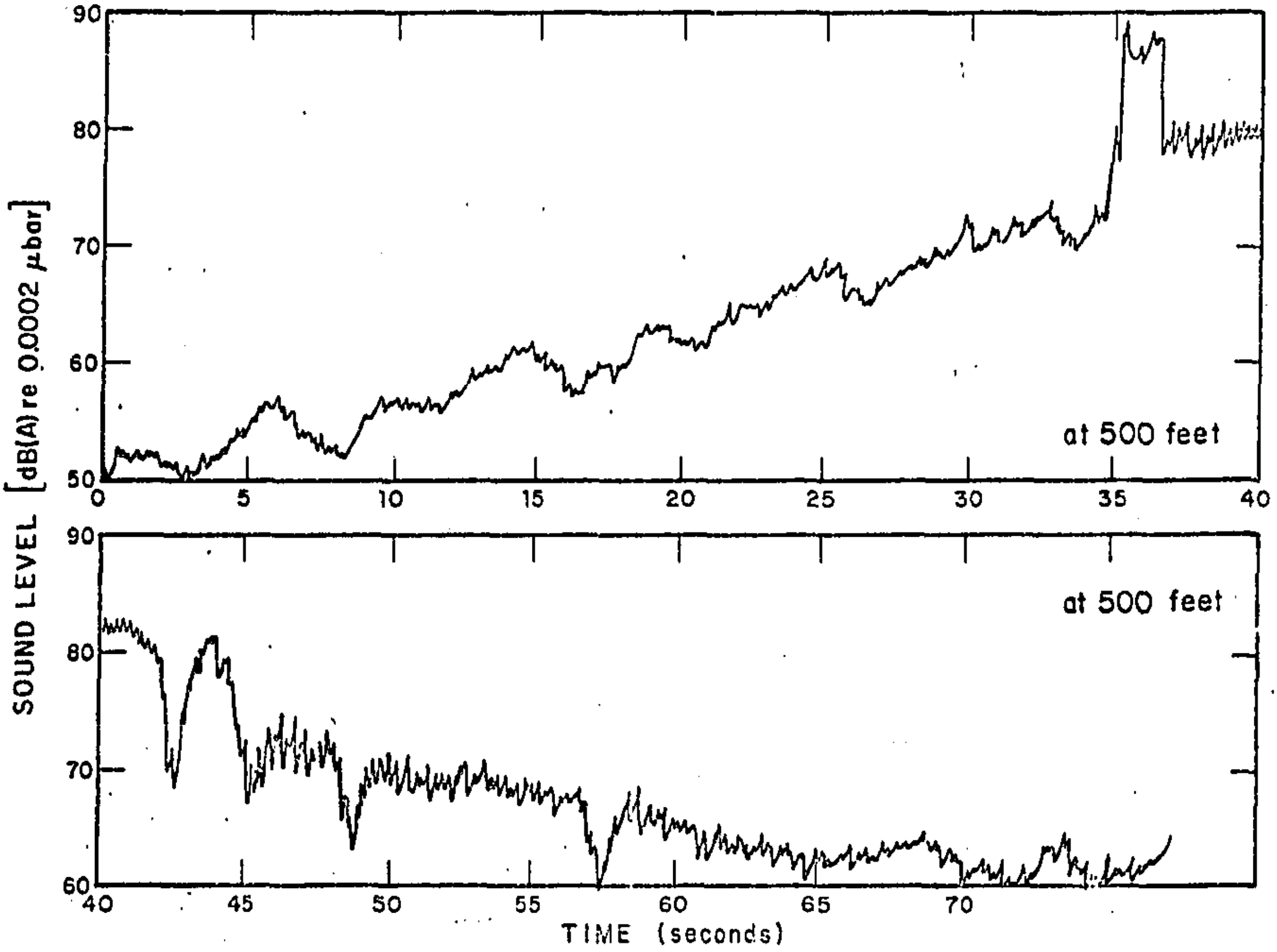

SOUND LEVEL [dB(A) re 0.0002 μbar]
90
80
70
60
50
0
5
10
15
20
25
30
35
40
at 500 feet
90
80
70
60
40
45
50
55
60
65
70
at 500 feet
TIME (seconds)

FIG. B.3.8. (CONT.)

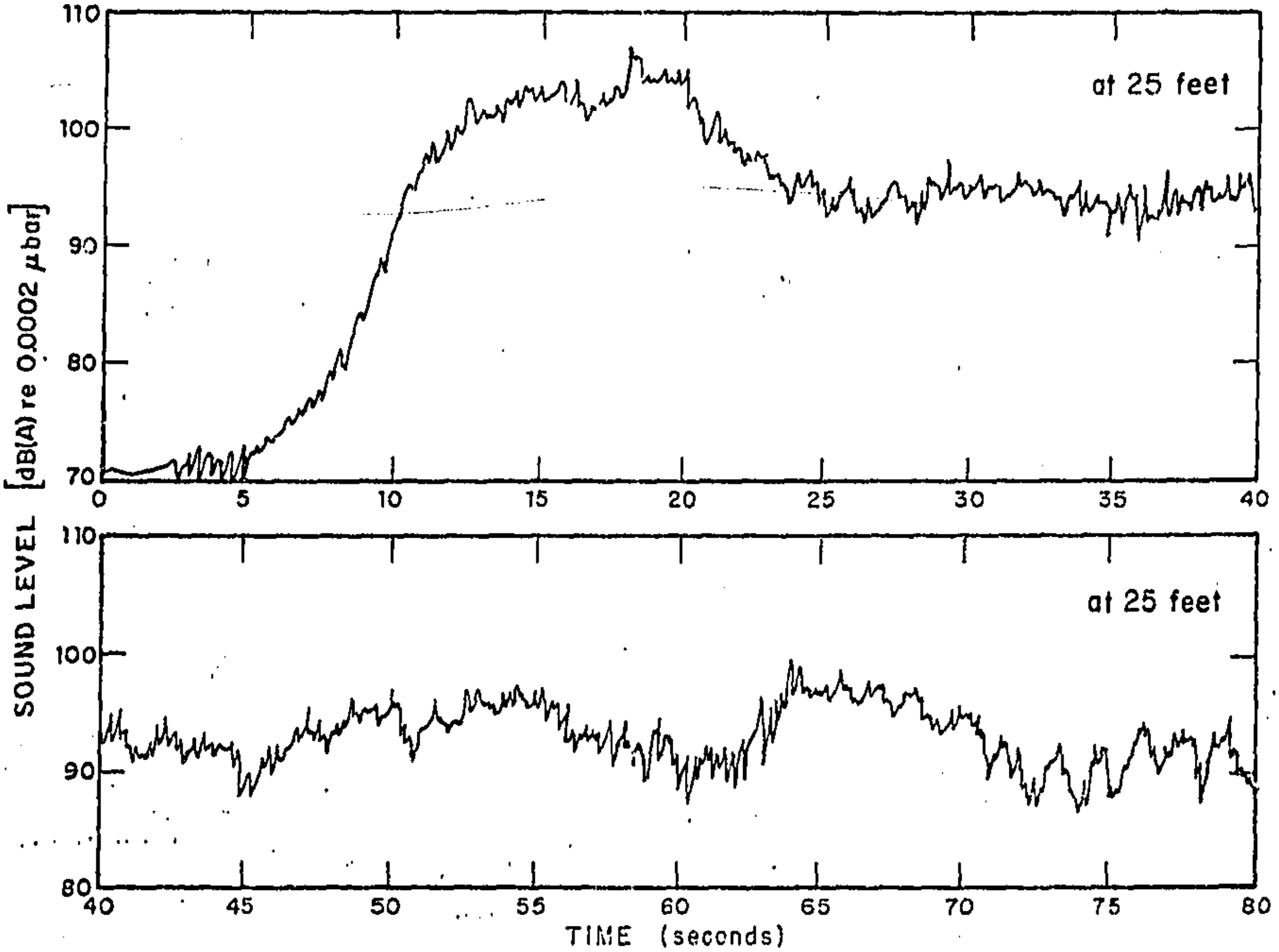


FIG. B.3.9. TRAIN NO. 3, FREIGHT, 14000 hp (5 EMD GP 40's), 57 LOADED CARS, 9 EMPTIES (6,490 TONS) GOING DOWN A 2% GRADE AT 25 mph (WITH DYNAMIC BRAKE)

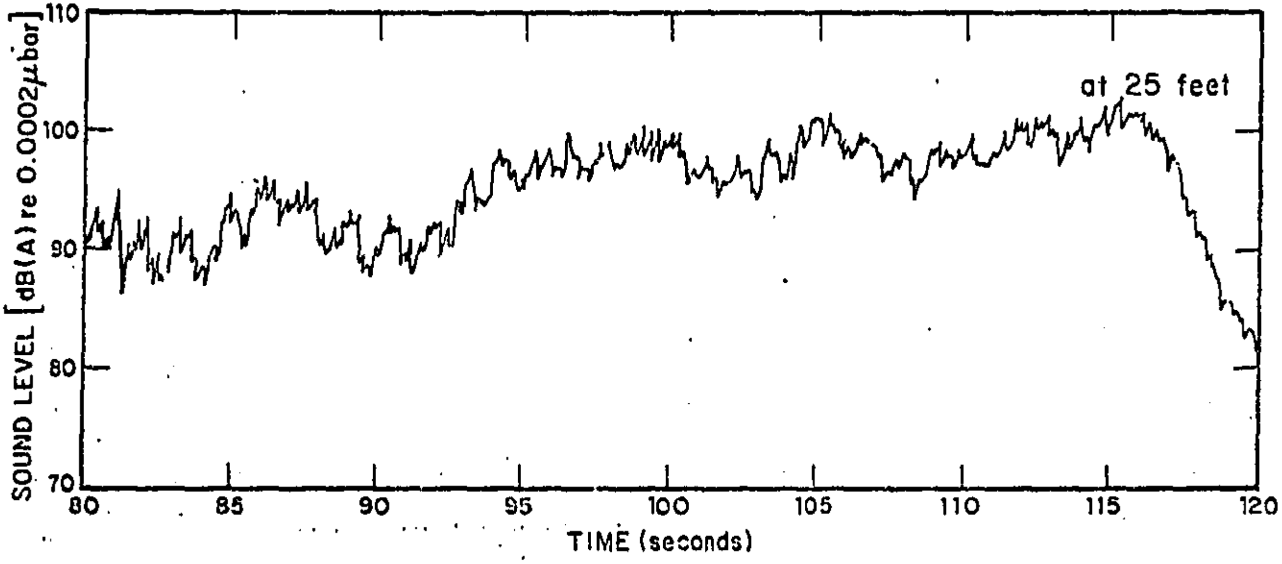

SOUND LEVEL [dB(A) re 0.0002μbar]
110
100
90
80
70
80
85
90
95
100
105
110
115
120
TIME (seconds)
at 25 feet

FIG. B.3.9. (CONT.)

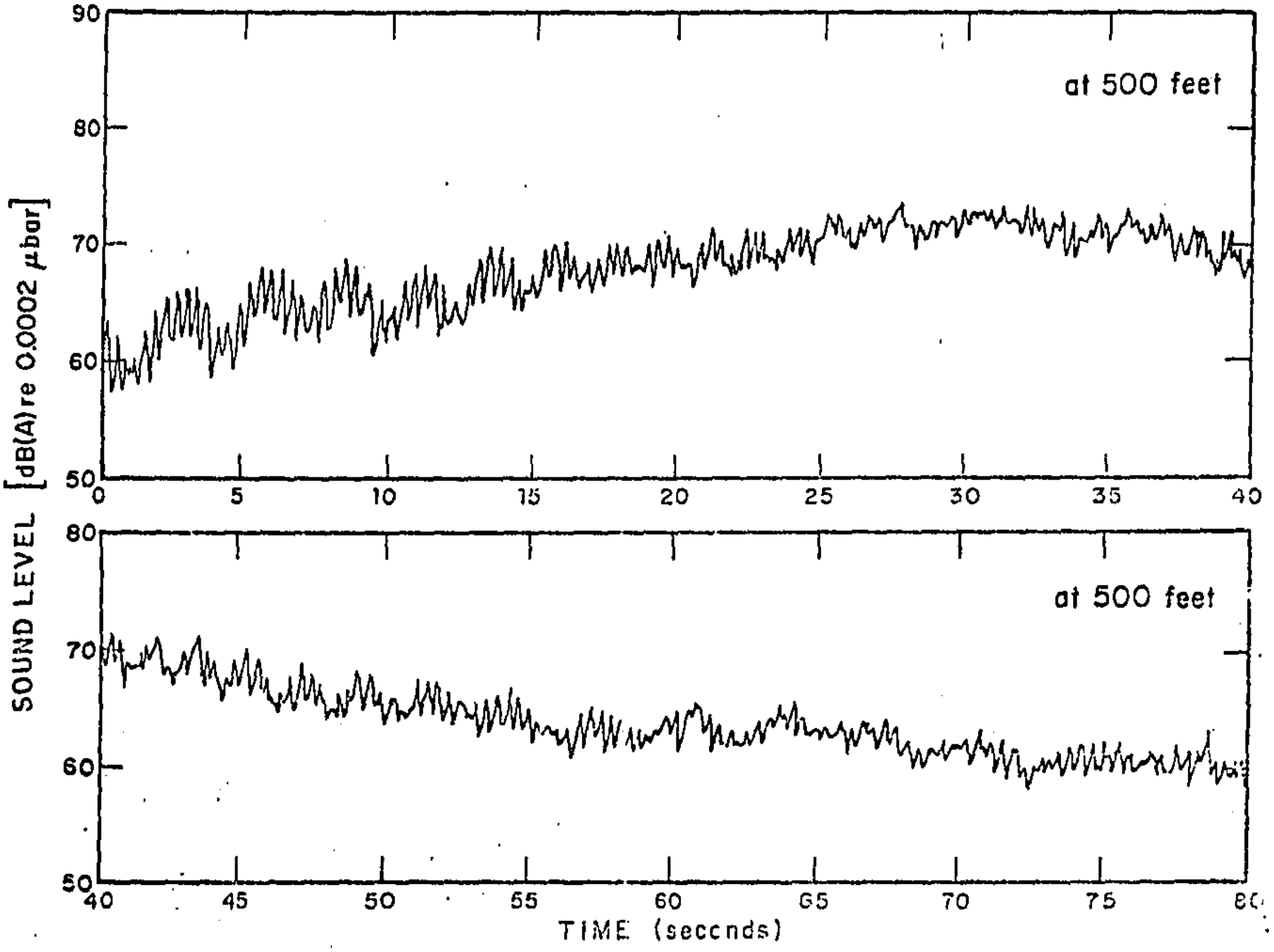

SOUND LEVEL [dB(A) re 0.0002 μbar]
at 500 feet
90
80
70
60
50
0
5
10
15
20
25
30
35
40
at 500 feet
80
70
60
50
40
45
50
55
60
65
70
75
80
TIME (seconds)

FIG. B.3.9. (CONT.)

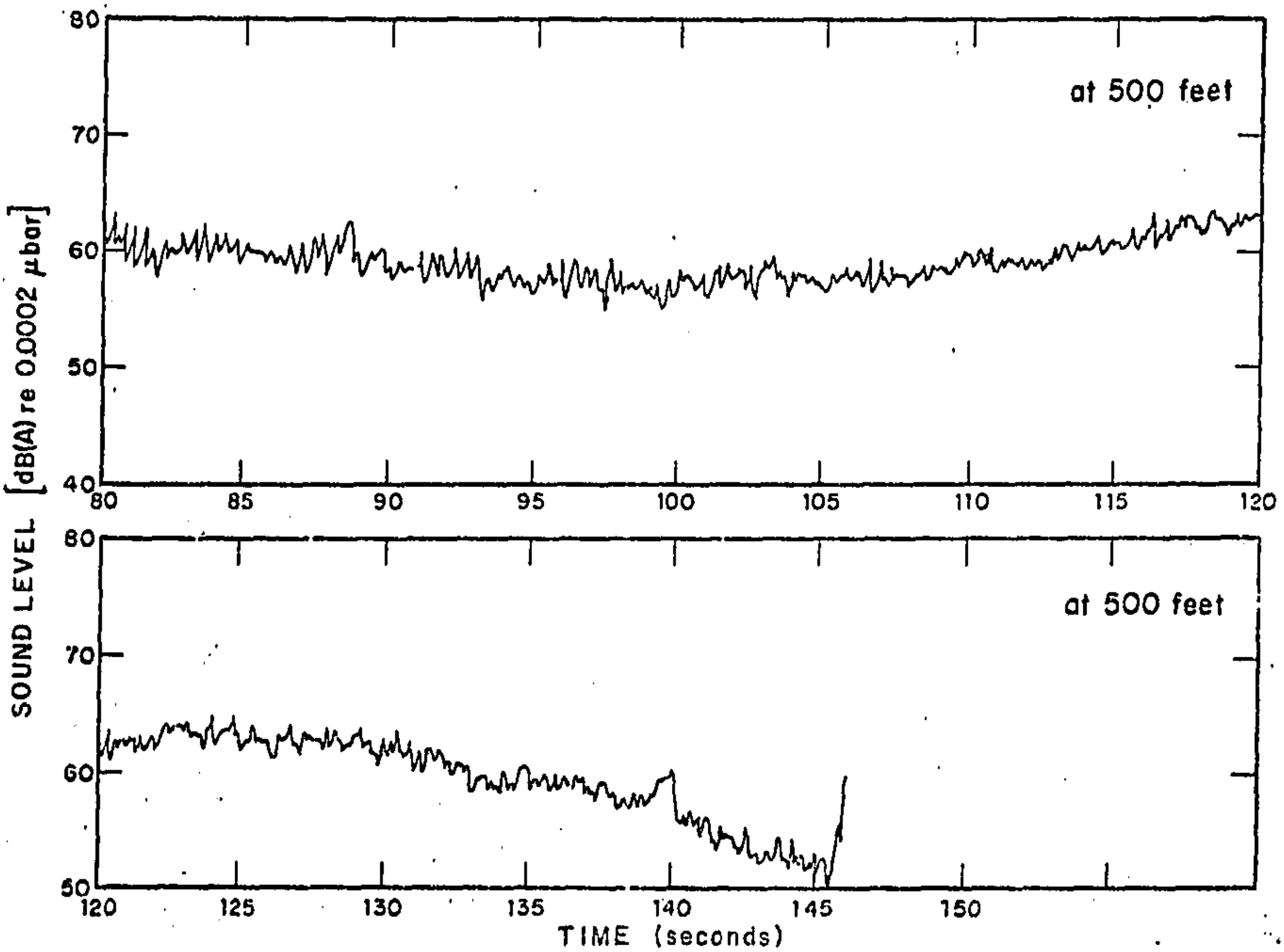

SOUND LEVEL [dB(A) re 0.0002 μbar]
at 500 feet
80
70
60
50
40
80
85
90
95
100
105
110
115
120
at 500 feet
80
70
60
50
120
125
130
135
140
145
150
TIME (seconds)

FIG. B.3.9. (CONT.)

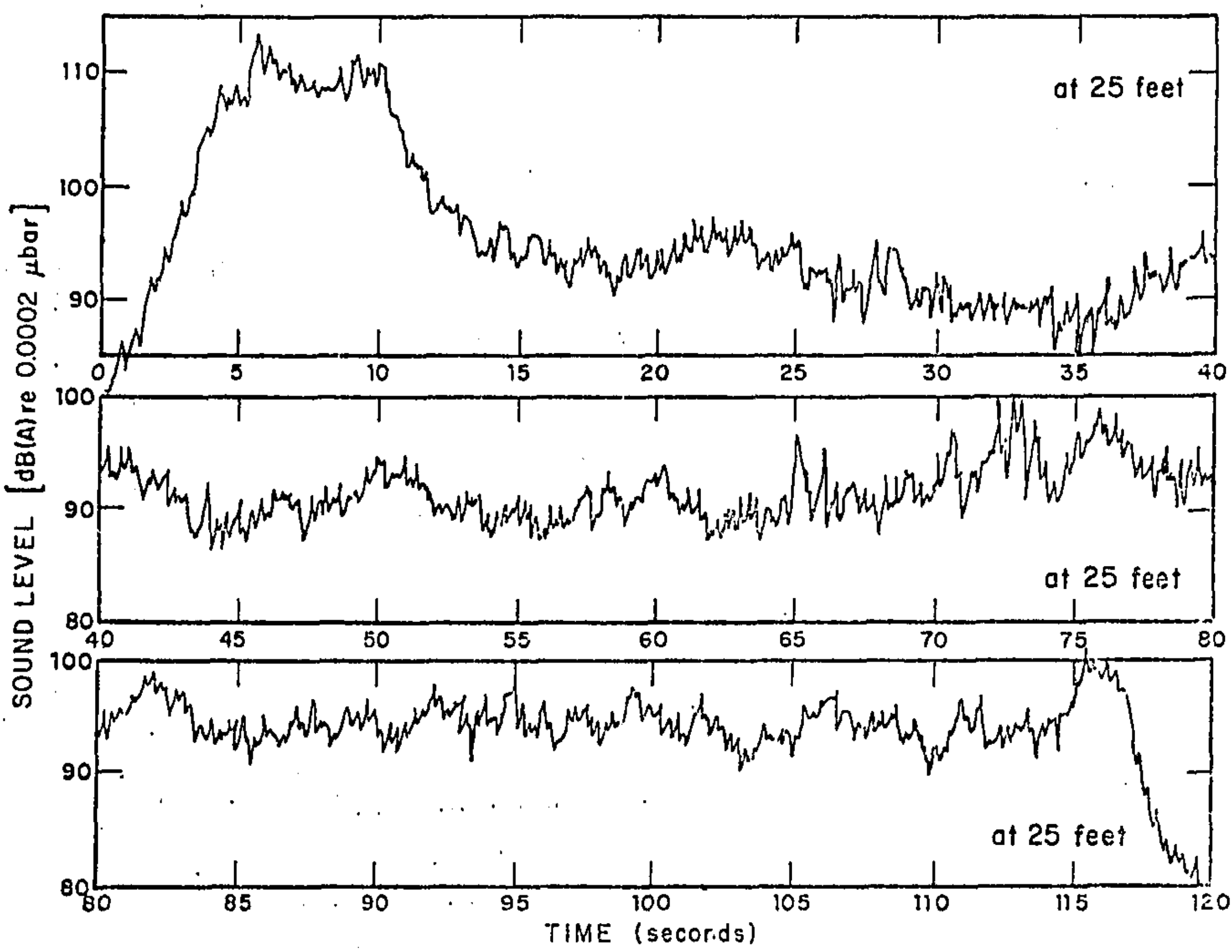


FIG. B.3.10. TRAIN NO. 9, FREIGHT, 10,800 hp (3 EMD GP 40's) 41 LOADED CARS, 16 EMPTIES (3,506 TONS) GOING DOWN A 2% GRADE AT 20 mph (WITH DYNAMIC BRAKE)

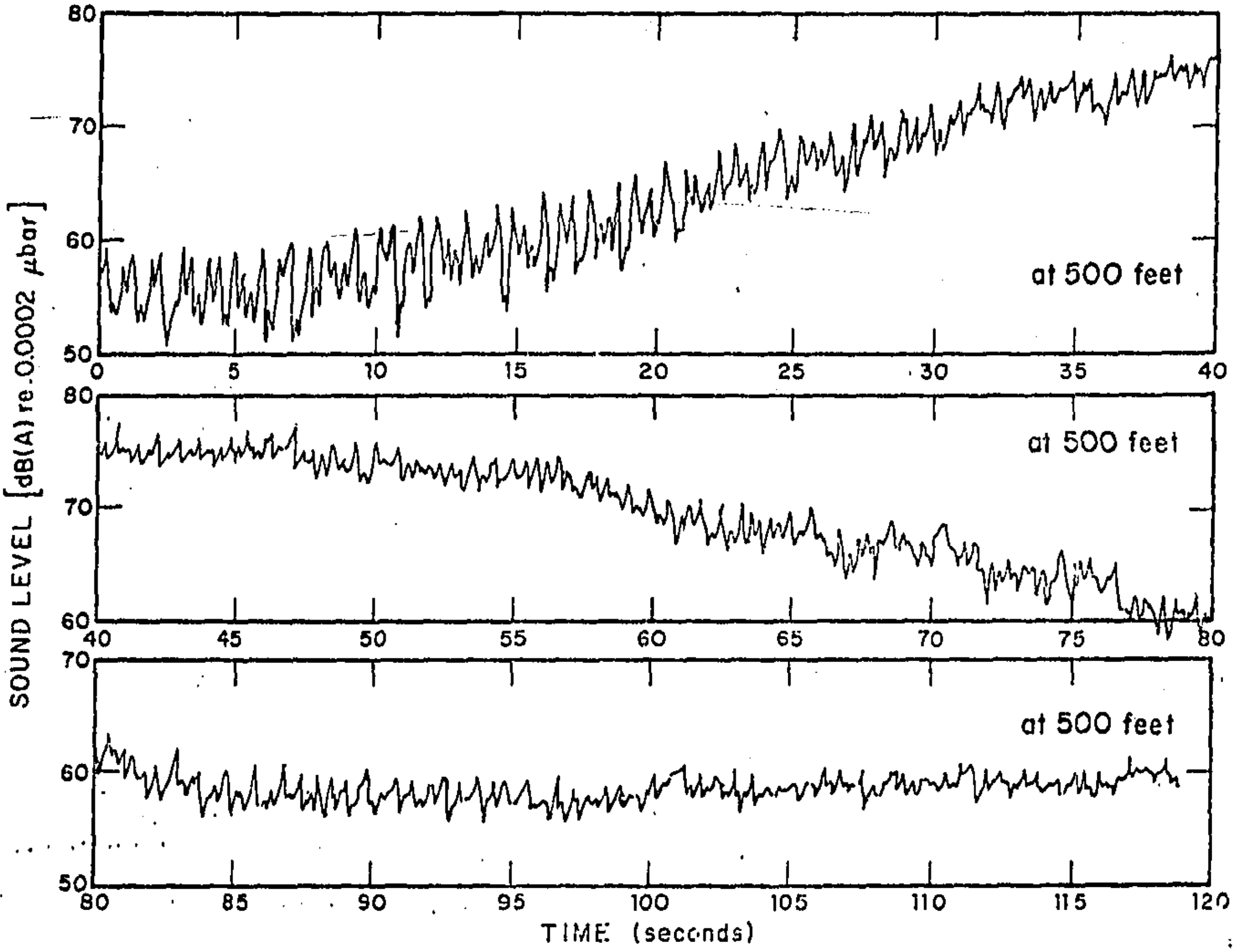


FIG. B.3.10. (CONT.)

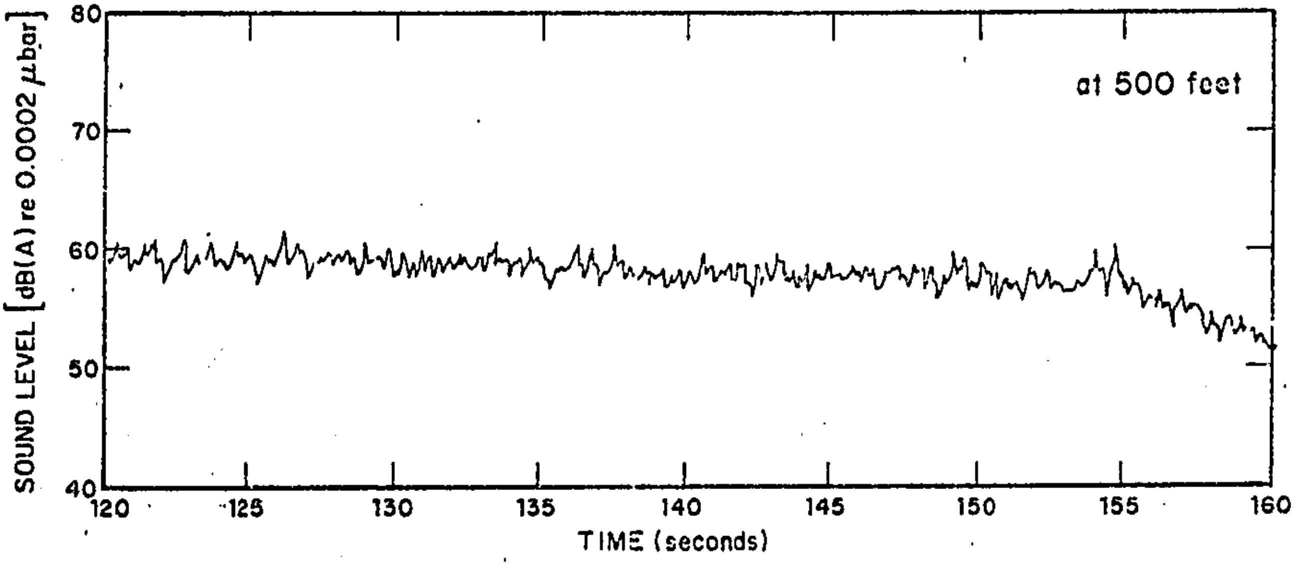


FIG. B.3.10. (CONT.)

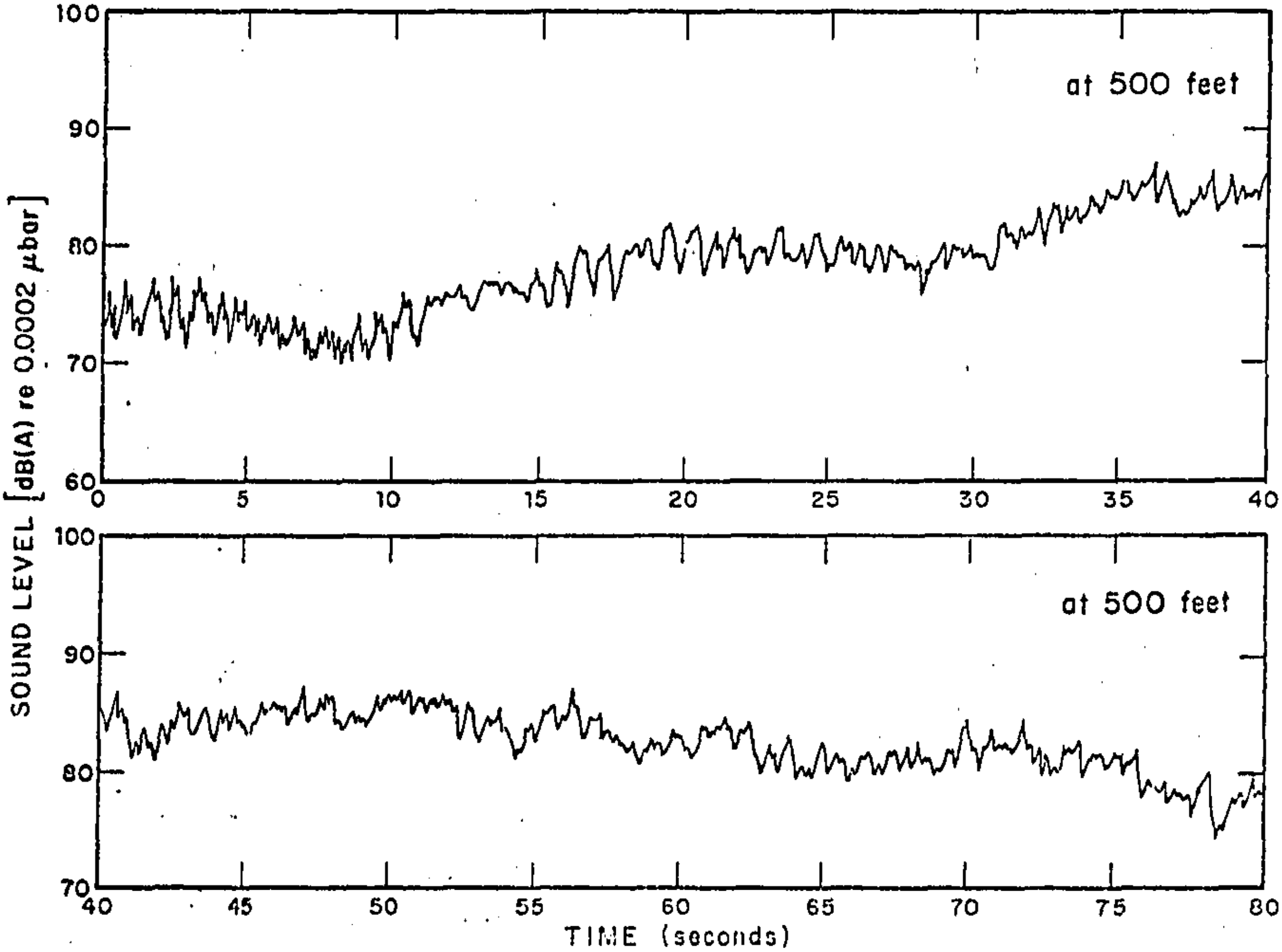


FIG. B.3.11. TRAIN NO. 5, FREIGHT, 13,300 hp (4 UNITS), 38 LOADED CARS, 27 EMPTIES (4,373 TONS) CLIMBING A 2% GRADE AT 15 mph

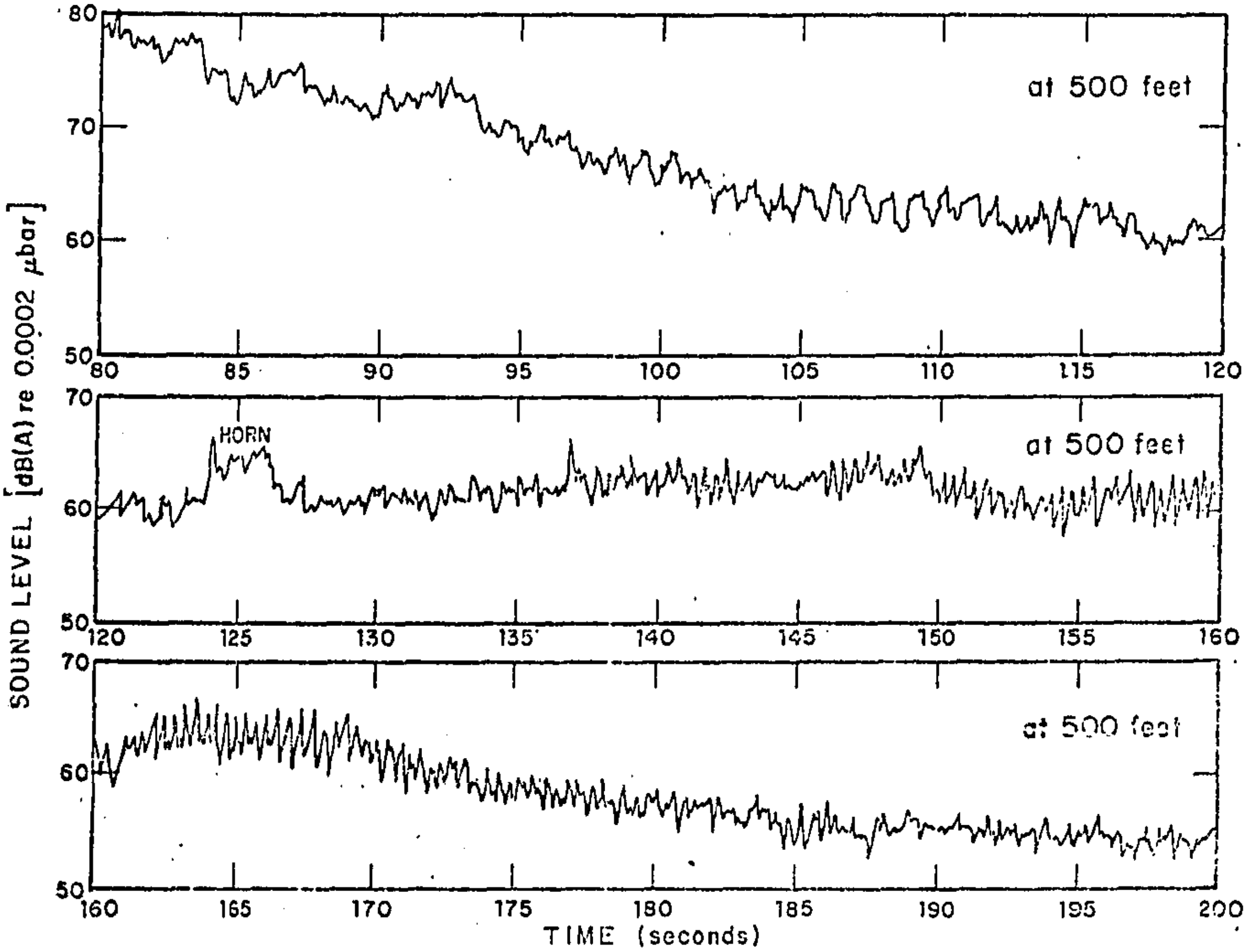


FIG. B.3.11. (CONT.)

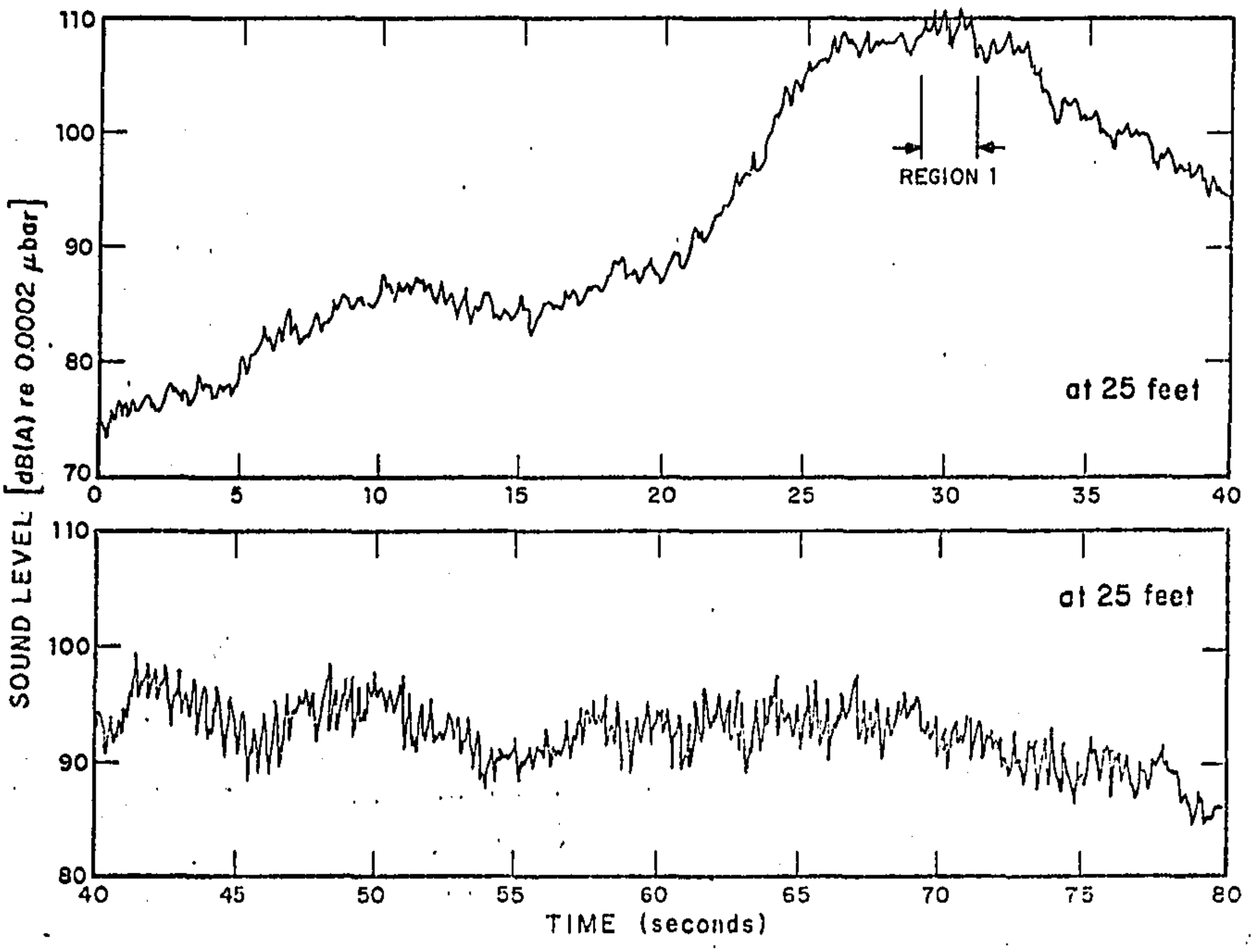


FIG. B.3.11. (CONT.)

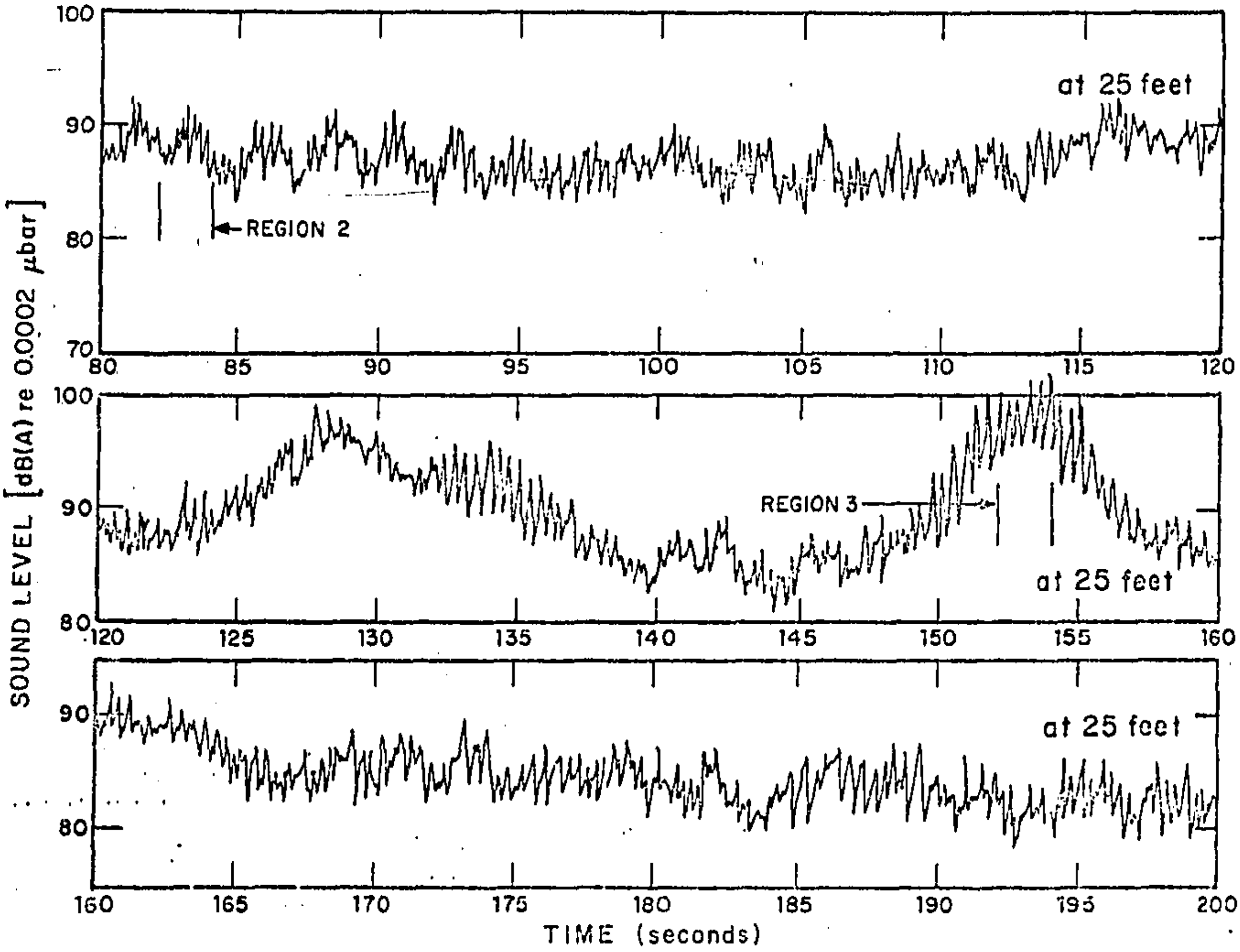


FIG. B.3.11. (CONT.)

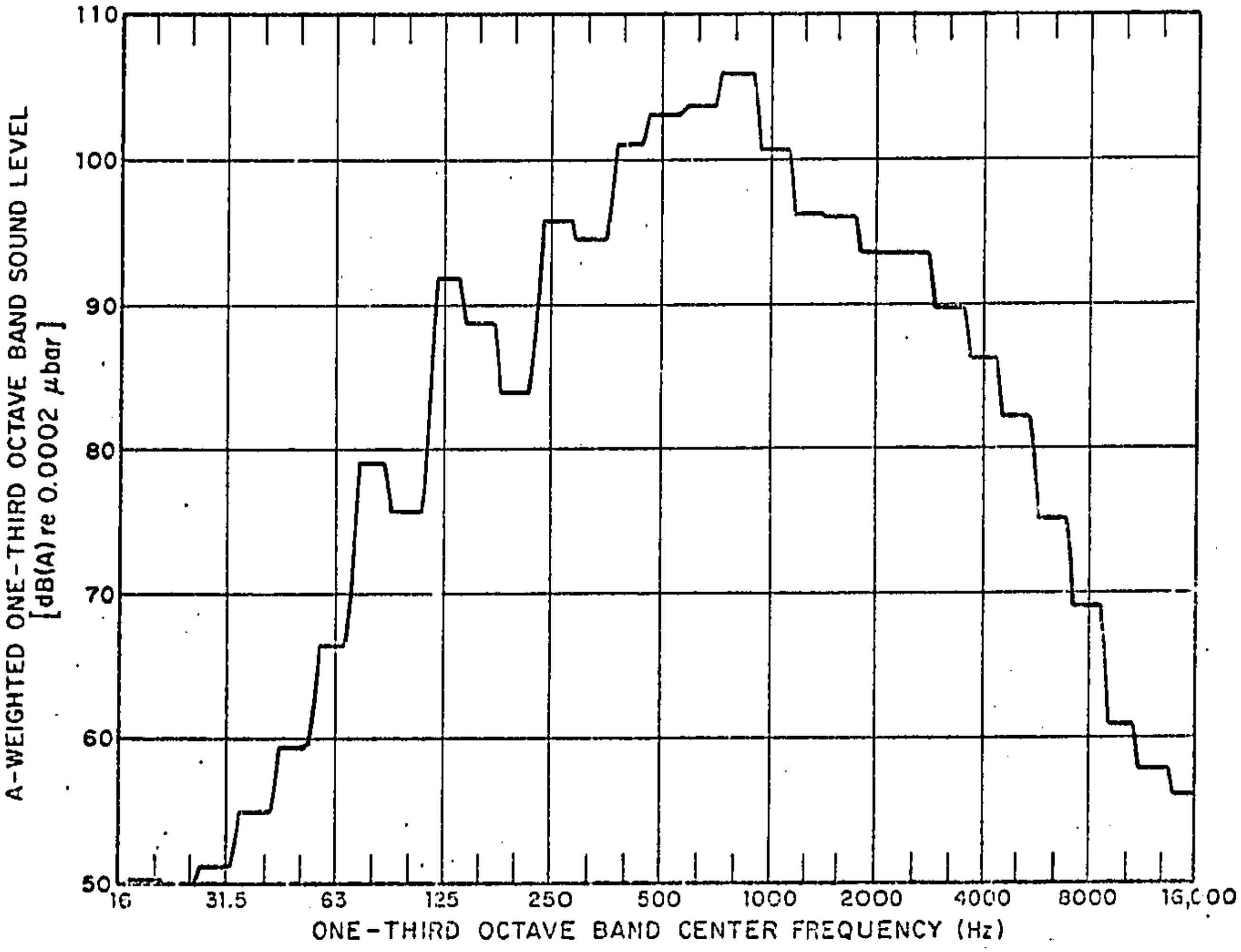


FIG. B.3.12 FREQUENCY ANALYSIS OF EARLY PORTION OF TRAIN NO. 5 NOISE AT 25 FT, REGION 1

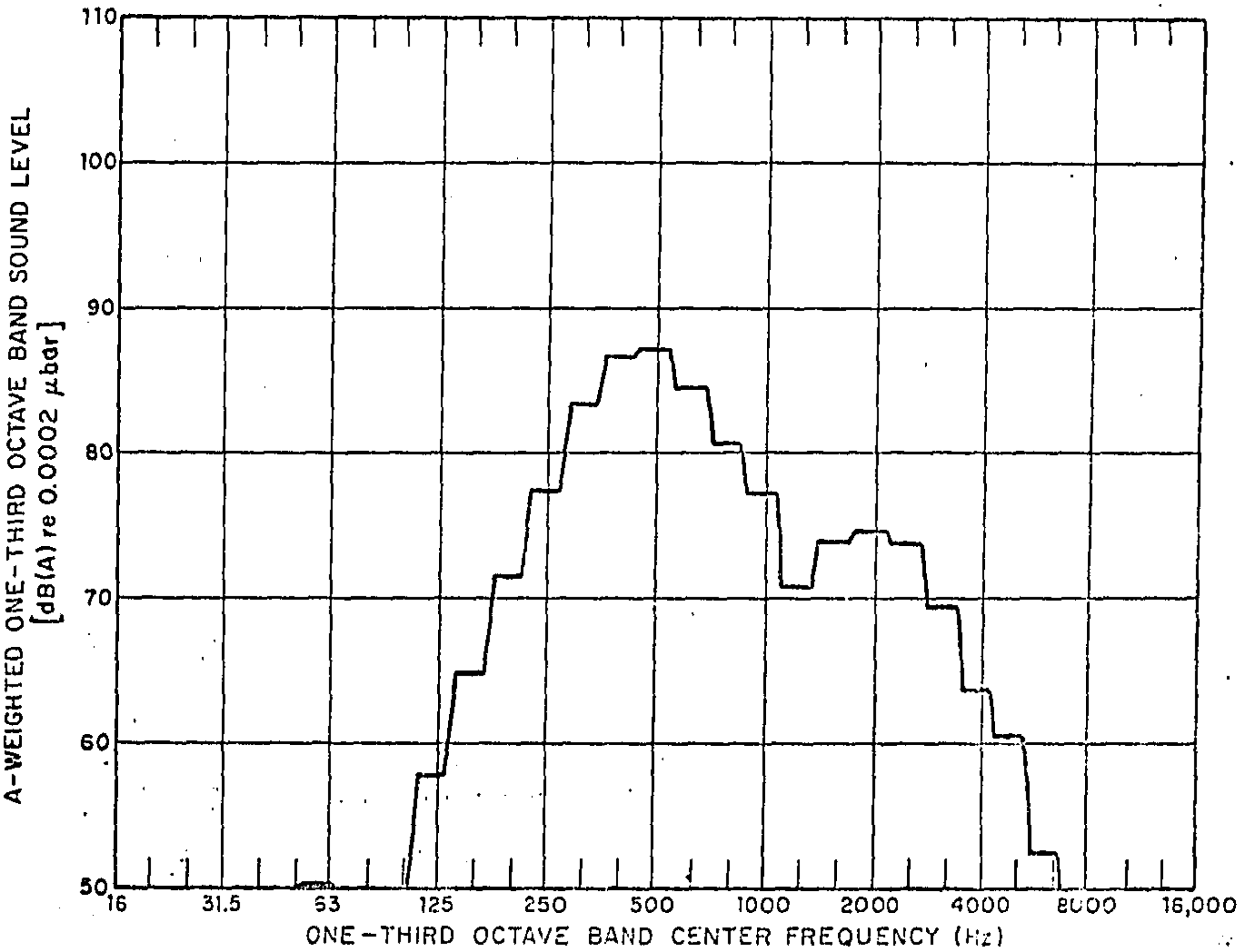


FIG. B.3.13(a) FREQUENCY ANALYSIS OF LATE PORTIONS OF TRAIN NO. 5 NOISE AT 25 FT, REGION 2

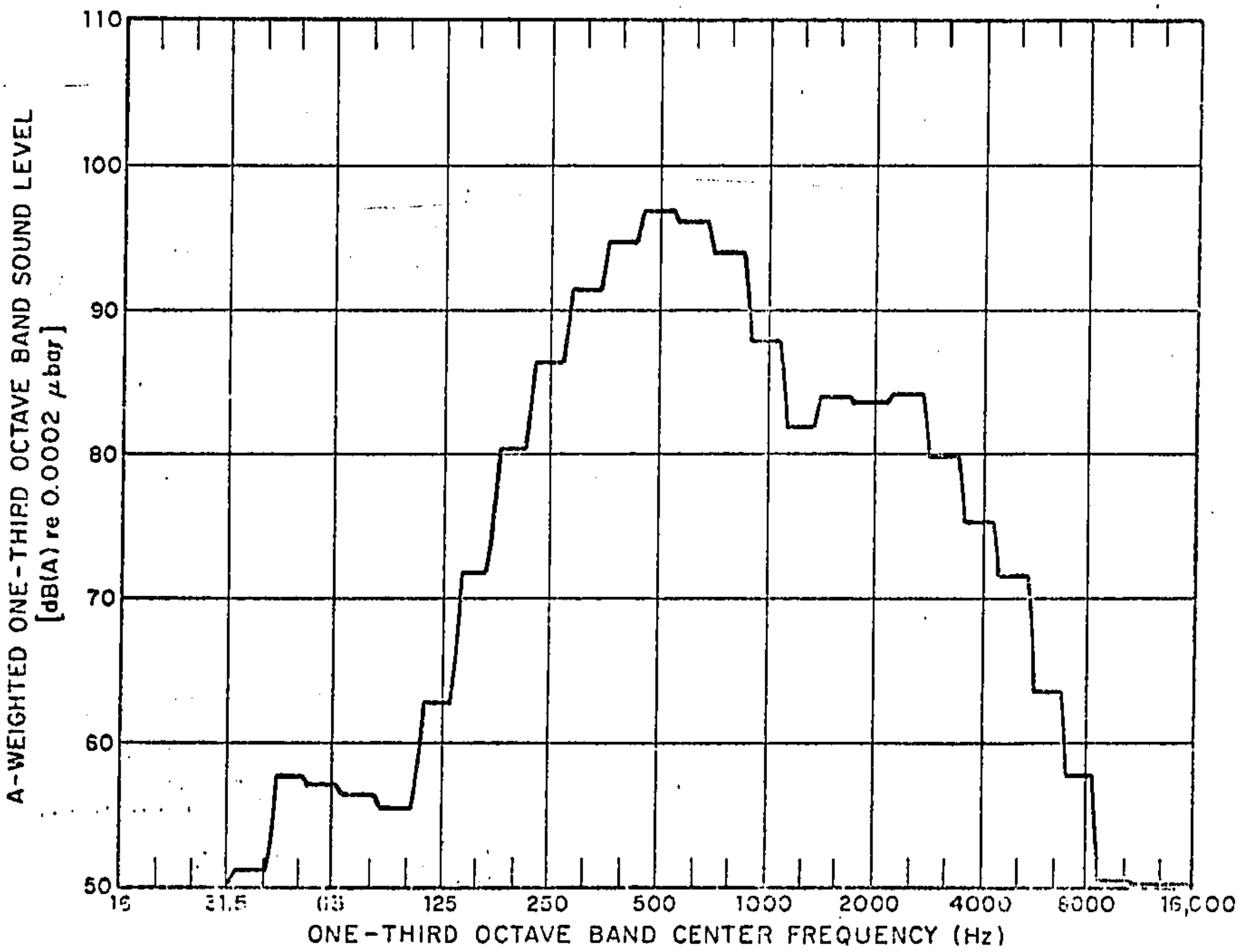


FIG. B.3.13(b). REGION 3

APPENDIX C: MEASUREMENT OF NOISE DUE TO RAILROAD YARD OPERATIONS

Noise measurements were made in two types of car-switching yards - flat yards and hump yards. In flat yards, locomotives push cars while the cars are switched from one track to another and are coupled to other cars. In hump yards, locomotives push cars up a hill, and the cars are slowed by mechanical devices called retarders and diverted by automatic switches onto selected tracks as the cars roll down the hill.

C.1 North Yard (Flat), Denver, Colorado

On May 2 and 3, 1973, BBN personnel measured noise in and outside Denver and Rio Grande Western's North Yard, in Denver, Colorado. Measurements were made near the noise sources, near the boundary of the yard, and at a point in the community outside of the yard.

Figure C.1.1 is a map of North Yard and the surrounding area. Switching locomotives were moving along the first six or seven sets of tracks on the east side of the yard. The locomotives were pushing individual cars into other cars, and assembled cars were being towed out of the assembly area. In addition to the noise due to switching locomotives and car impact, loudspeakers were issuing voice communications. The measured noise levels were recorded on magnetic tape for later analysis.

The instrumentation was the same as that described in Appendix B.1. Figures C.1.2, C.1.3, and C.1.4 show the configuration of the equipment. One microphone was located 275 ft away from the center of the easternmost classification track, near the boundary of the yard. A second microphone was located either at a point 25 ft away from the center of the easternmost classification track or 1300 ft away from the center of that track, outside of the railroad property. The measurements near the track were made to relate noise levels at the boundary of the yard to the events which generated them. The measurements outside of the railroad property were made to relate the sound in the community to the sound at the boundary of the yard.

Measurements were made during three different time periods. The first measurements were made at the 25-ft point and the 275-ft point simultaneously from 4:30 p.m. to 6:30 p.m. on May 2, 1973. The temperature was 59°F. The relative humidity was 37%. There were scattered clouds, and the wind was blowing at 1 to 4 mph from the south (parallel to the tracks). The second set of measurements was made at the 275-ft and the 1300-ft point simultaneously from 4:00 a.m. to 6:00 a.m. on May 3, 1973. The temperature was 36°F, and the relative humidity was 30%. The wind was negligible (less than 1 mph). Measurements were made at the same locations between 1:00 p.m. and 2:00 p.m. on May 3, 1973. Meteorological conditions were approximately the same as the conditions under which measurements were made on the previous afternoon.

Figure C.1.5 shows a segment of the time history of noise at measurement position Number 1 in North Yard. Figure C.1.6 shows selected events from a single 20-min recording of noise measured around 2:00 p.m. at measurement position Number 2, which was near the boundary of North Yard. Figure C.1.7 shows selected events from noise recordings taken in the early morning at measurement position Number 3, about 1000 ft from the boundary of North Yard. The measurement locations are shown in Figs. C.1.1 through C.1.4.

The measured noise levels shown in Figs. C.1.5 through C.1.7 are consistent with levels predicted by the methods described in Sec. 4. The 80 dB(A) horn noise levels in Fig. C.1.7 correspond to a locomotive positioned directly west of position 3. The measured levels for impact noises are approximately the same for all three measurement locations, corresponding to impacts occurring at an equal distance from all three measurement points, or at a point directly west of position 3. The impact noise level at 50 ft from the generating event that can be inferred from that configuration agrees reasonably well with other measured values shown in Fig. 2.1. More measurements of noise in flat yards are needed, and the individual sources need to be studied in detail. However, the cursory measurements presented here are useful for statistical analysis of community noise levels, and the measurements allow us to draw one specific conclusion — that locomotive horns were the source of the loudest railroad noise in the community during the time that these measurements were made. More study will be needed to determine the frequency of occurrence of the various noises.

C.2 Cicero Yard (Hump), Chicago, Illinois

On May 16 and 17, 1973, BBN personnel measured noise in and around Burlington Northern's Cicero Yard, in Chicago, Illinois. Measurements were made near the noise sources, near the boundary of the yard, and at points in the community outside of the yard.

Figure C.2.1 is a map of the Cicero Yard and the surrounding area. Humping operations were underway in the central region of the yard, with accompanying car impacts in the classification area below the hump. On the south side of the yard, switching locomotives moved flat cars into and out of a "piggyback" loading area where truck trailers were loaded onto the flat cars by a hydraulic hoist. in addition to the noise from switching locomotives, "piggyback" operations, retarder noise, and car impact, voice and warning signals issued from various loudspeakers. The measured noise levels were recorded on magnetic tape for later analysis.

The instrumentation was the same as described in Appendix B.1. Figures C.2.2 through C.2.7 show the configuration of the test equipment. Those figures also show the areas surrounding the various test sites.

During the morning of May 16, 1973, measurements of retarder noise and car impact noise were obtained. Figure C.2.2 shows the retarders and measurement equipment. The map in Fig. C.2.1 shows the location of the test equipment. The microphone was 10 ft away from the closest retarder beam. As cars moved through the three pairs of retarders shown on the map, the levels of squeal noise were recorded along with a designation of the retarder involved. The three pairs of group retarders were manufactured by ABEX Corporation. A sound level meter and a tape recorder were operated in a portable mode to measure the noise due to car-car impact. The impact noise was measured at a distance of 10 ft.

While the retarder and impact noise were being measured on the morning of May 16, the temperature ranged from 53°F – 59°F, and the relative humidity ranged from 36% – 39%. There was a wind blowing at 6 – 10 mph from the northeast. The sky ranged from dark to partly cloudly.

From 4:30 p.m. to 6:30 p.m. on May 16, noise measurements were made at the southern boundary of the yard – Ogden Avenue – and at a point in the surrounding community – West 30*th* Street.

Those points are marked on the map in Fig. C.2.1 and are pictured in Figs. C.2.3 and C.2.4. The temperature was 57°F, and the relative humidity was 33%. There was a 0 – 5 mph wind from the north (from the yard, toward the community). Measurements were made at those two locations again between 3:30 a.m. and 7:30 a.m. the following morning, May 17. The temperature was 47°F, the relative humidity was 37%, and there was no measurable wind.

Between 9:00 a.m. and 10:00 a.m. on May 17, additional noise measurements were made at the West 30*th* Street location. Simultaneous measurements were made at the West 29*th* Street location, shown on the map in Fig. C.2.1 and in the photographs in Fig. C.2.5. The temperature was 64°F, the relative humidity was 32%, and a wind was blowing at 3 – 4 mph, with gusts to 7 mph.

Between 10:45 a.m. and 11:30 a.m. on May 17, simultaneous measurements were made at the northern boundary of the yard and at a point in the community north of the yard. The boundary site was on 26*th* Street, and is shown on the map in Fig. C.2.1 and in the photographs in Fig. C.2.6. The community site was at 25*th* Place and 53*rd* Street, shown on the map in Fig. C.2.1 and in the photographs in Fig. C.2.7. The meteorological conditions were the same as the conditions during the 10:00 a.m. tests at West 29*th* and West 30*th* Streets, described above.

Over a hundred retarder squeals were measured within the boundaries of the Cicero yard at the locations shown in Figs. C.2.1 and C.2.2. Figure C.2.8 shows the results of six measurements of retarder squeals. The variations of the amplitudes, durations, and shapes of the squeals are indicative of the variation of the more than one hundred squeals.

Figure C.2.9 gives the frequency content of five of the squeals shown in Fig. C.2.8. Figure C.2.9 shows that the frequency at which the maximum sound occurs does not vary much from one type of generating event to another.

Figure C.2.10 shows the distribution of the sound levels of the squeals. The significance of Fig. C.2.10 is discussed in Sec. 4.4.

Over 25 car-car impact noises were measured within the boundaries of Cicero yard at the locations shown in Fig. C.2.1. Figure C.2.11 gives the results of 6 measurements of car-car impact. The six impacts shown in Fig. C.2.11 are representative of all of the measured impacts. Figure C.2.12 gives the frequency content of a typical impact.

Figure C.2.13 shows the manner in which the sound levels of the measured impacts were distributed. The significance of the Fig. C.2.13 is discussed in Sec. 4.5.

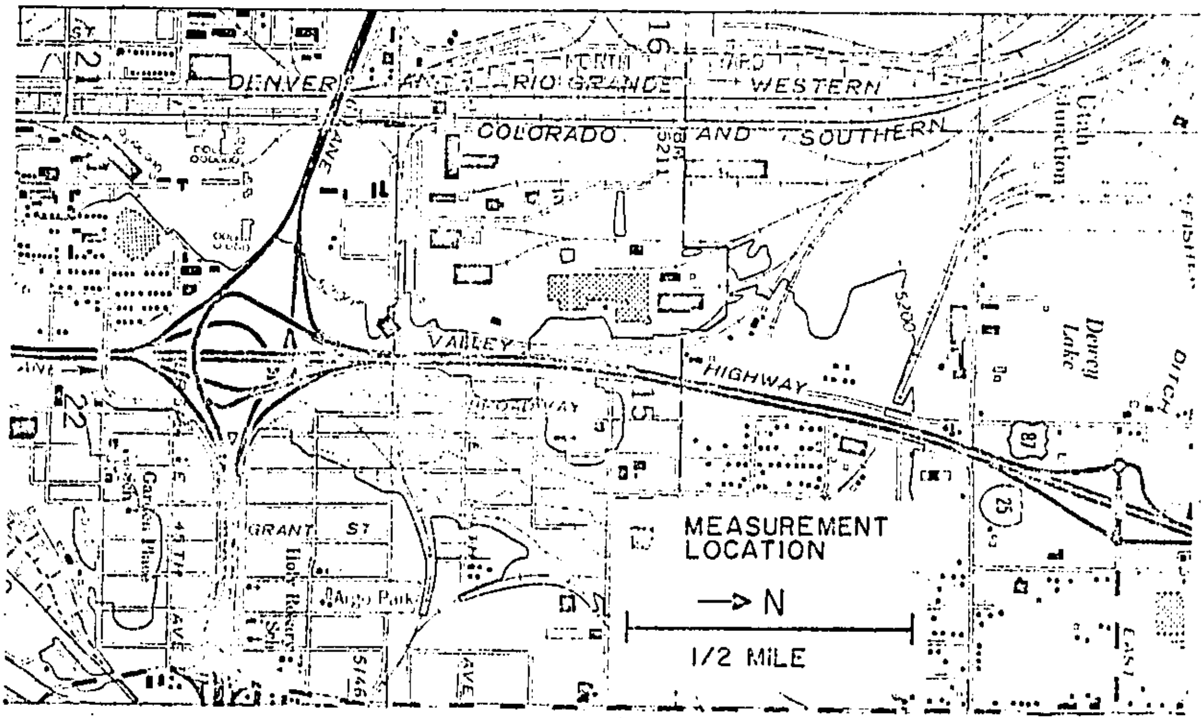
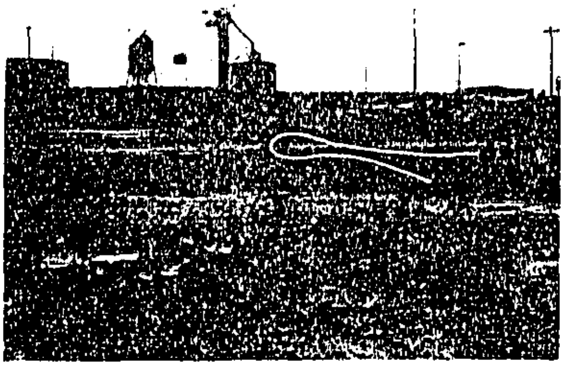
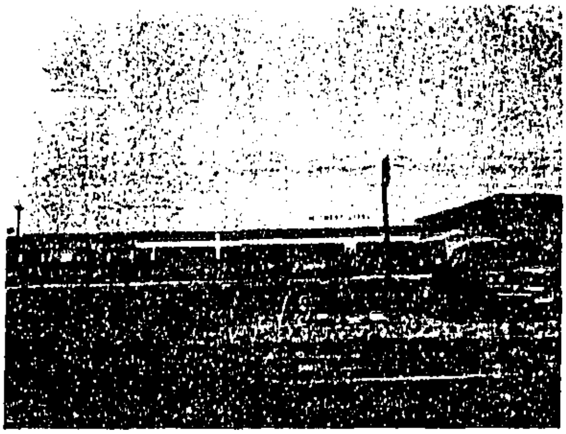


FIG. C.1.1. A MAP OF THE VICINITY OF NORTH YARD



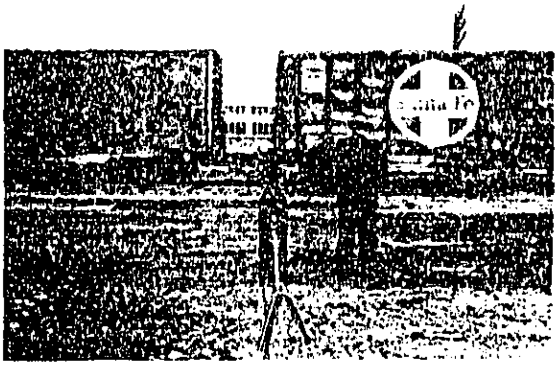
(a) Looking West Past Near Field Measurement Point



(b) Looking East Past Near Field Measurement Point

FIG. C.1.2. PHOTOGRAPHS OF THE NORTH YARD NEAR FIELD MEASUREMENT POINTS

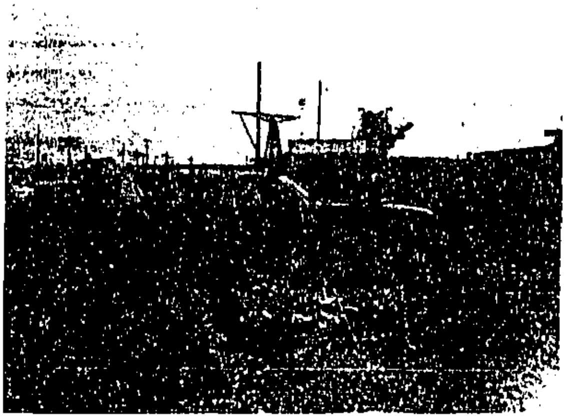
BLACK COPY



(c) A Train Passing Behind (East) the Near Field Measurement Point (Not Part of the Yard Switching Operation)

(d) Looking North Past the Near Field Measurement Point

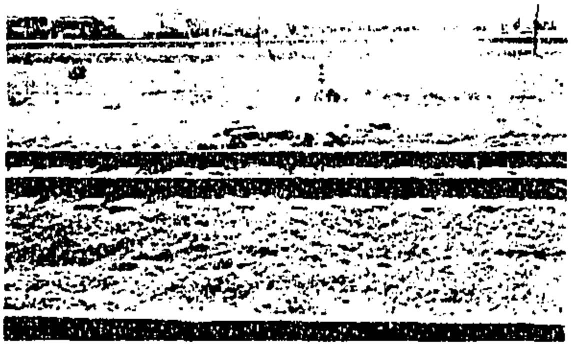
FIG. C.1.2. (CONT.)



(e) Looking South Past the Near Field Measurement Point

FIG. C.1.2. (CONT.)

BLACK COPY



(a) Looking West Past the Far Field Measurement Point

(b) Looking East Past the Far Field Measurement Point

FIG. C.1.3. PHOTOGRAPHS OF THE NORTH YARD FAR FIELD MEASUREMENT POINTS

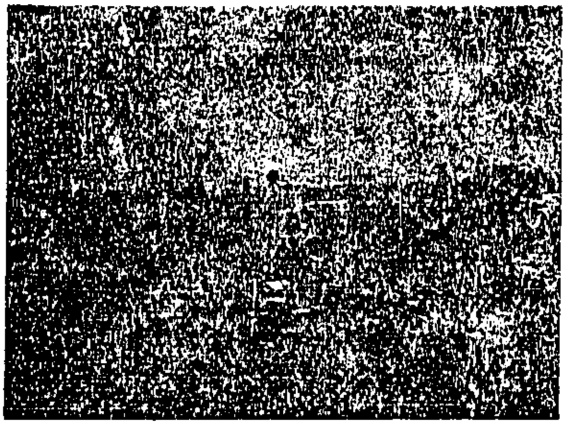
BLACK COPY

(c) Looking South Past the Far Field Measurement Point

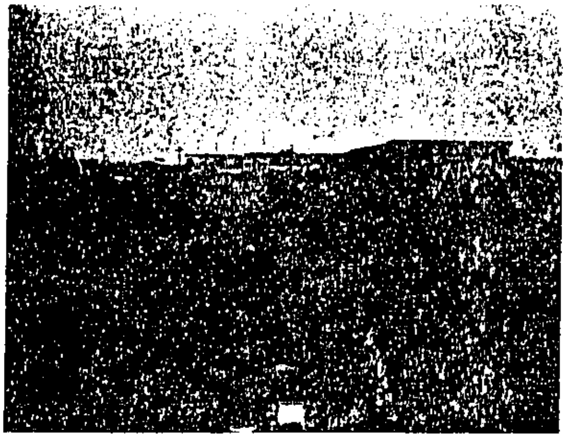
(d) Looking North Past the Far Field Measurement Point

FIG. C.1.3. (CONT.)

BLACK COPY



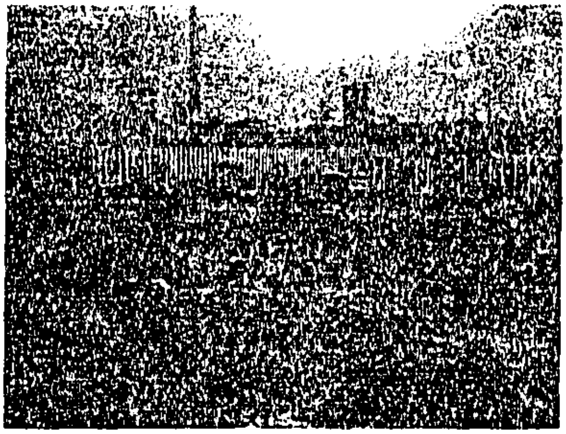
(a) Looking North Past the Fox Street Measurement Point



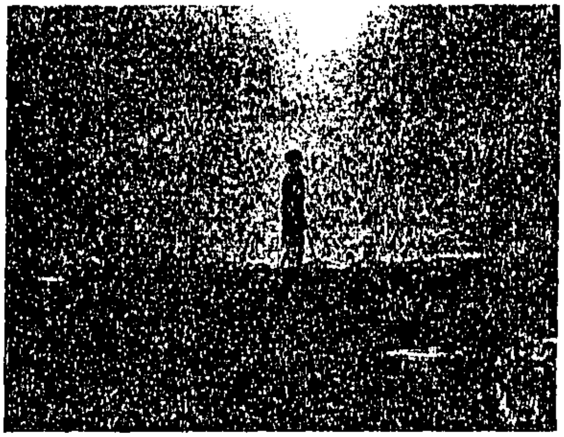
(b) Looking South Past the Fox Street Measurement Point

FIG. C.1.4. PHOTOGRAPHS OF THE COMMUNITY MEASUREMENT POINTS NEAR NORTH YARD

BLACK COPY



(c) Looking East Past the Fox Street Measurement Point



(d) Looking West Past the Fox Street Measurement Point, Toward the Yard

FIG. C.1.4. (CONT.)

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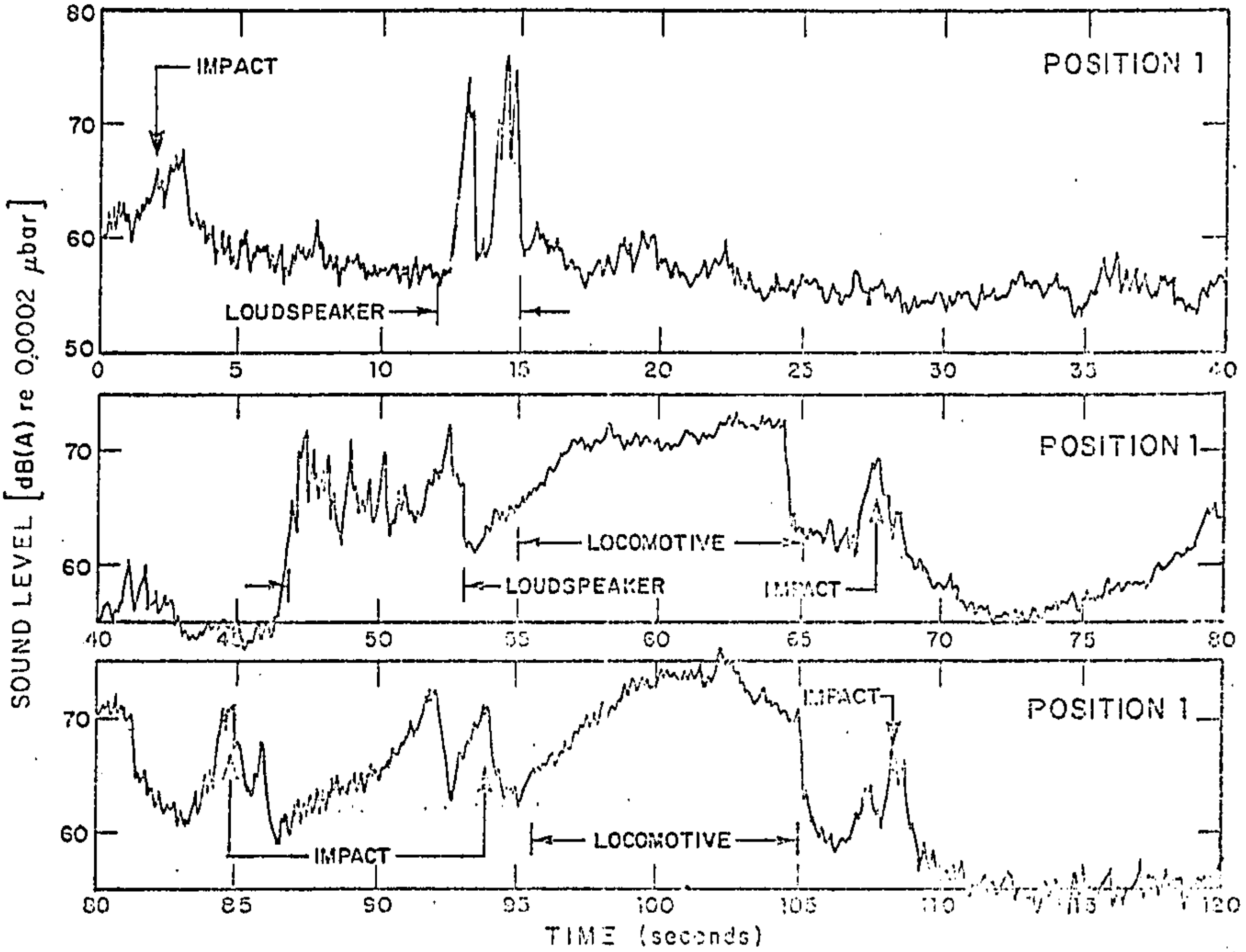


FIG. C.1.5 A SEGMENT OF THE TIME HISTORY OF NOISE IN NORTH YARD

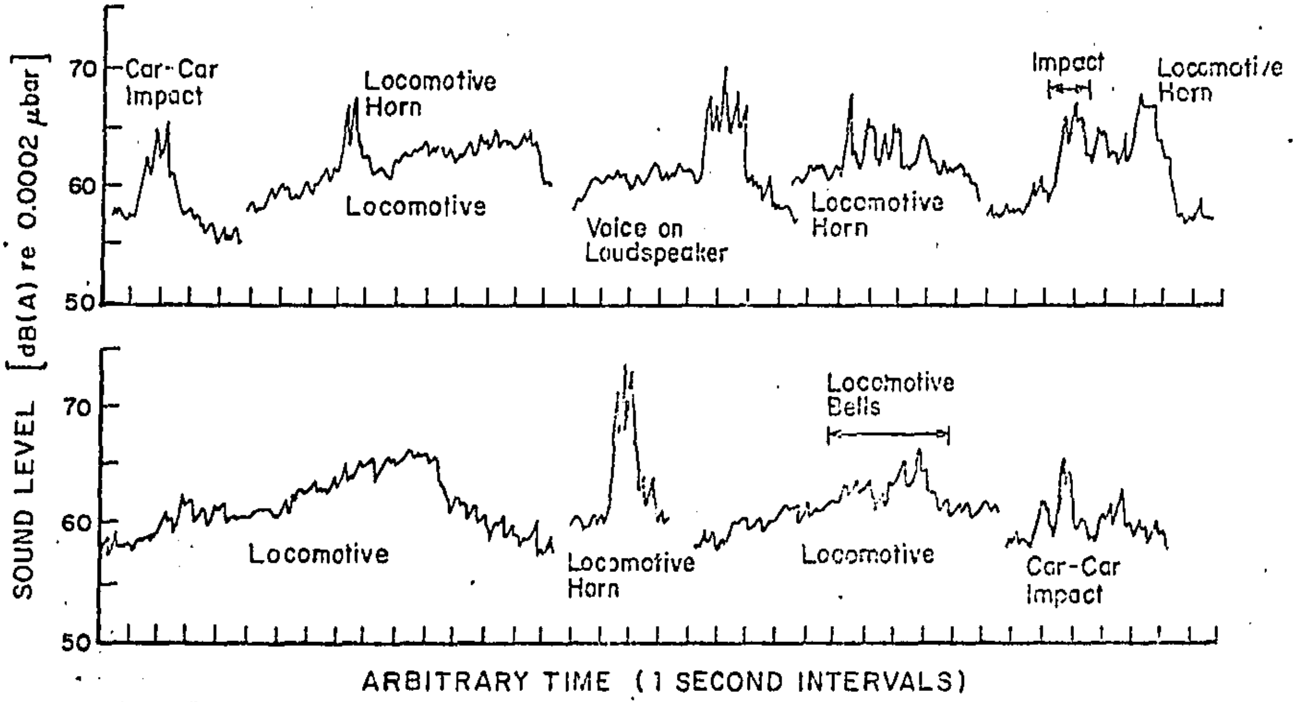


FIG. C.1.6 SELECTED EVENTS FROM A TIME HISTORY OF NOISE AT THE BOUNDARY OF NORTH YARD

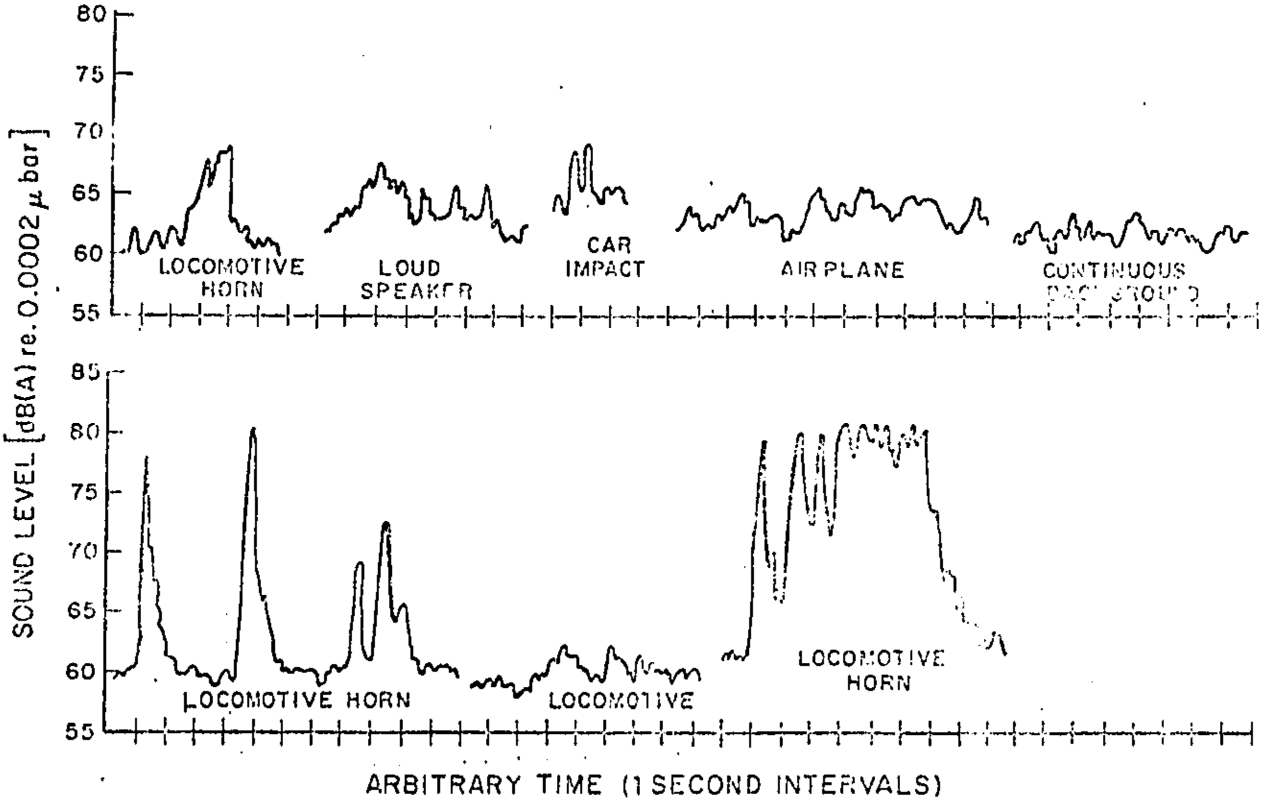


FIG. C.1.7 SELECTED EVENTS FROM A TIME HISTORY OF NOISE ABOUT 1000 FT FROM THE BOUNDARY OF NORTH YARD

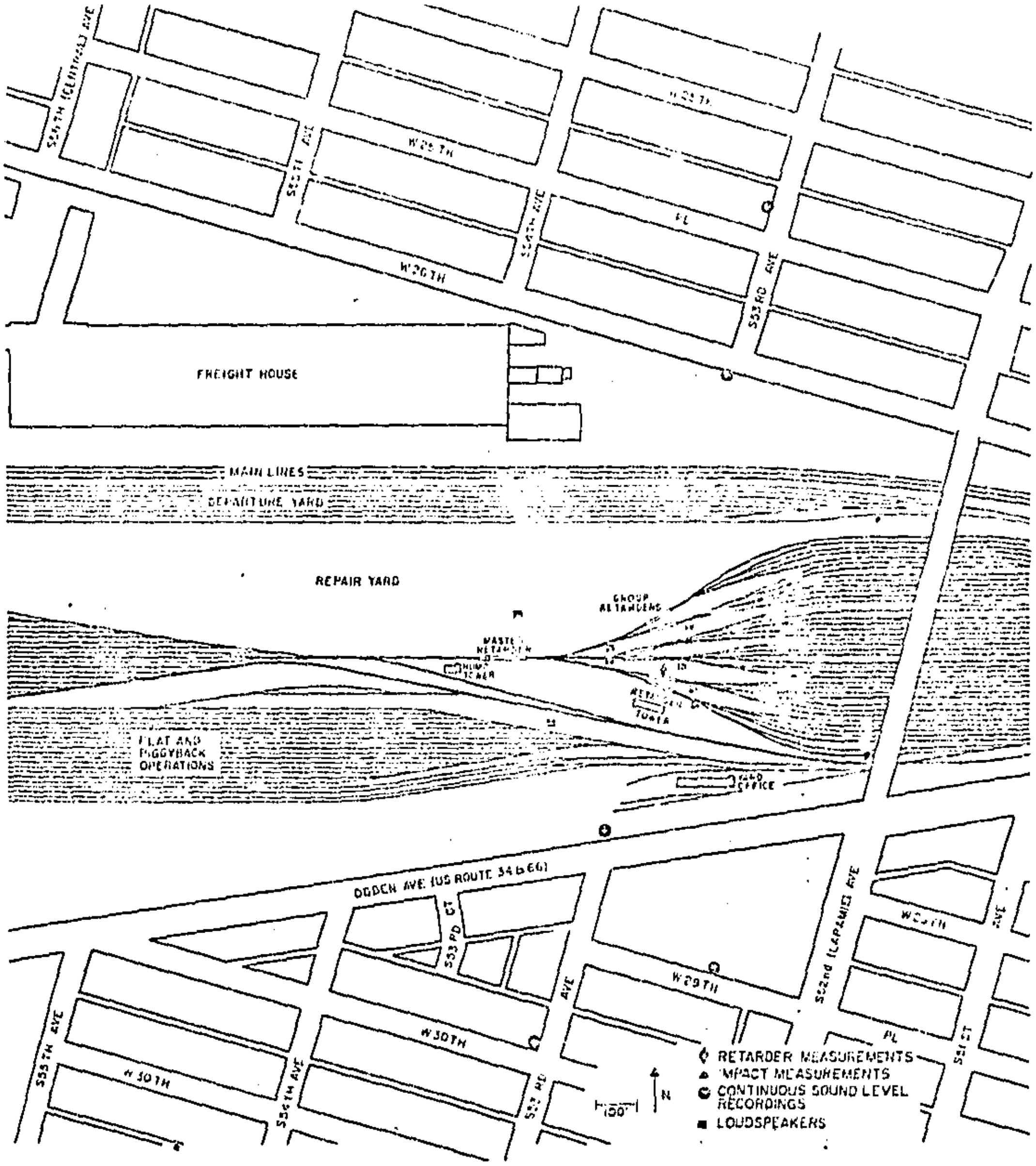
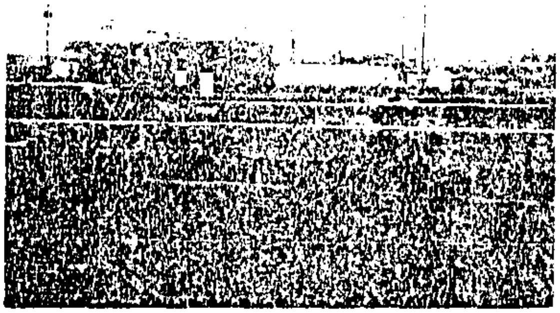
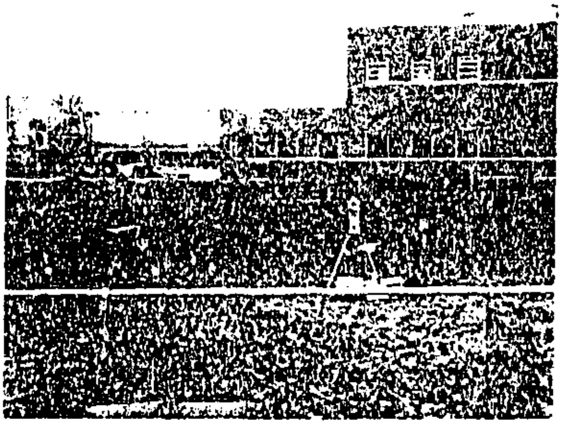


FIG. C.2.1. A MAP OF THE CICERO YARD

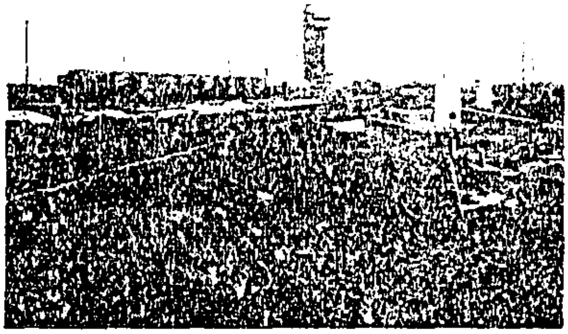


(a) Looking North, Toward 25th Place

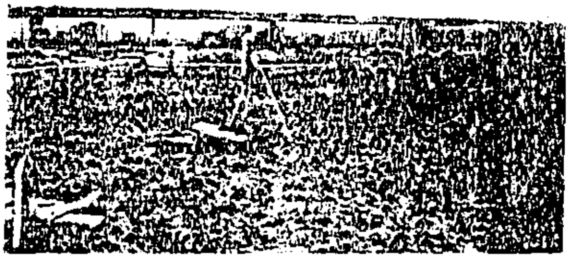


(b) Looking South, Toward 30th Street

FIG. C.2.2. PHOTOGRAPHS OF THE RETARDER MEASUREMENT POINT

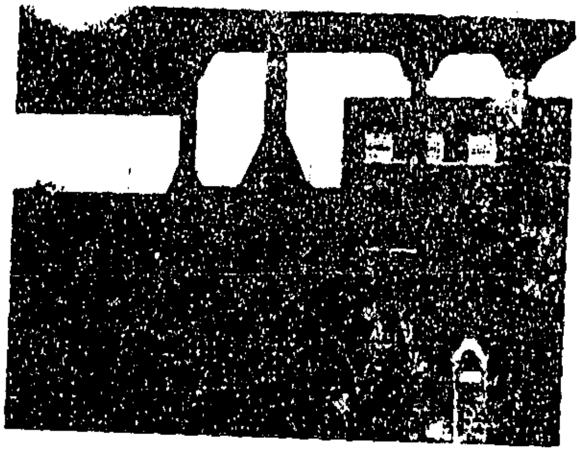


(c) Looking West, Up the Hump



(d) Looking East, into Classification Yard

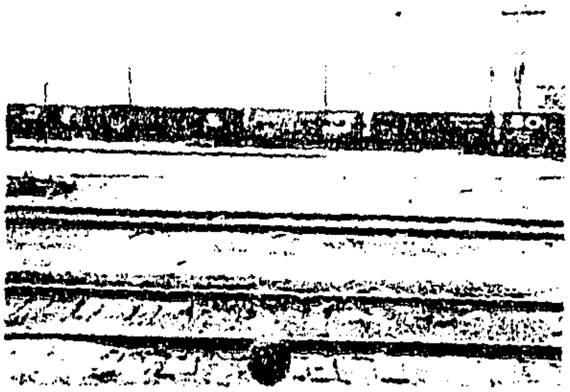
FIG. C.2.2. (CONT.)



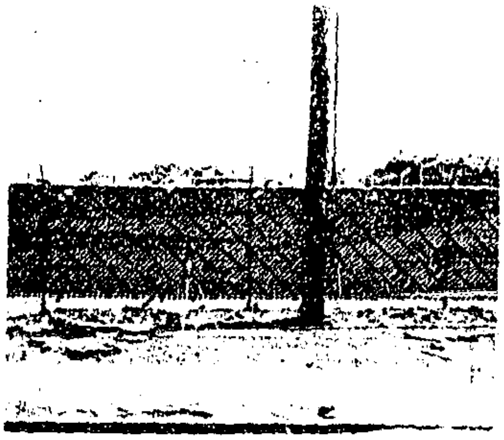
(e) Looking South, with Auto Carrier Passing the Observation Point

FIG. C.2.2. (CONT.)

BLACK COPY



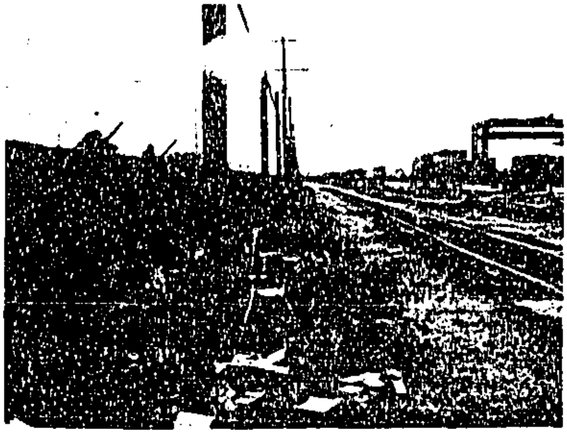
(a) Looking North, Toward 25th Place



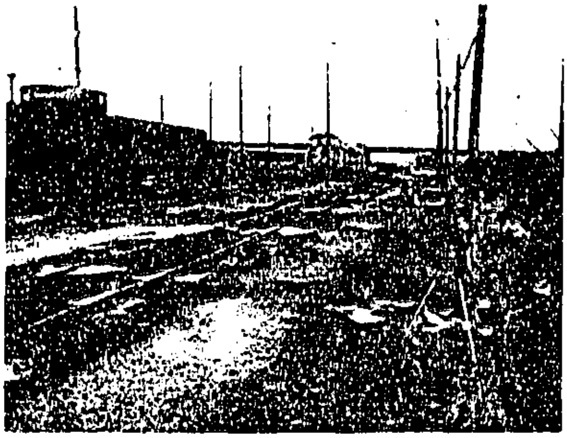
(b) Looking South, Toward 30th Street

FIG. C.2.3. PHOTOGRAPHS OF THE OGDEN AVENUE PERIMETER MEASUREMENT POINT

BLACK COPY



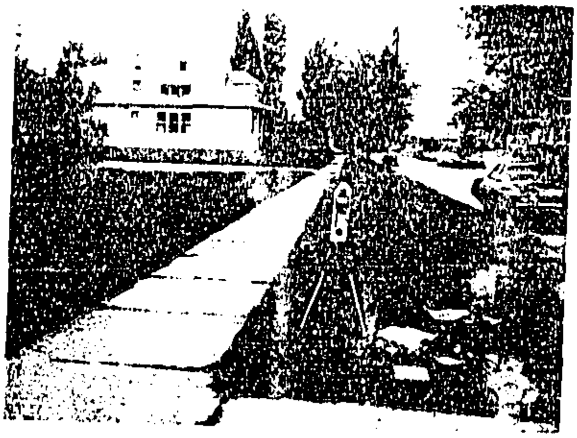
(c) Looking West



(d) Looking East

FIG. C.2.3. (CONT.)

BLACK COPY

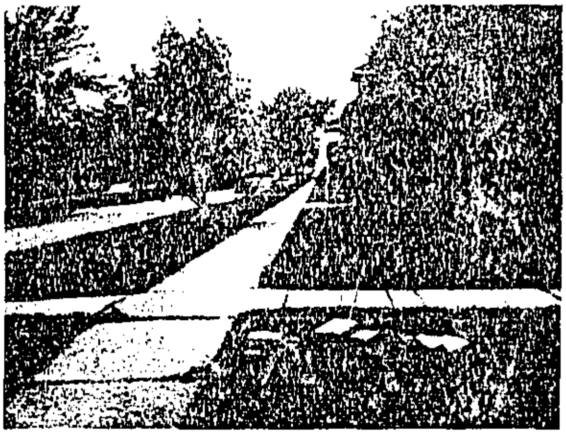


(a) Looking North, Toward Yard

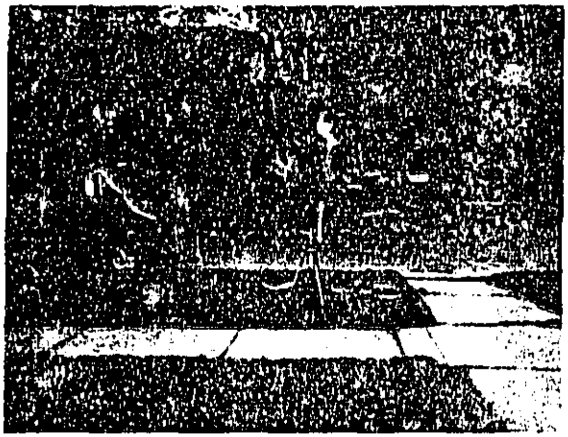
(b) Looking South, away from Yard

FIG. C.2.4. PHOTOGRAPHS OF THE WEST 30TH COMMUNITY MEASUREMENT POINT

BLACK COPY



(c) Looking West



(d) Looking East

FIG. C.2.4. (CONT.)

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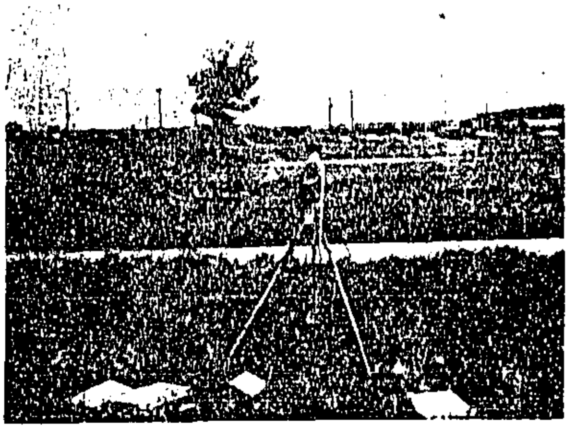
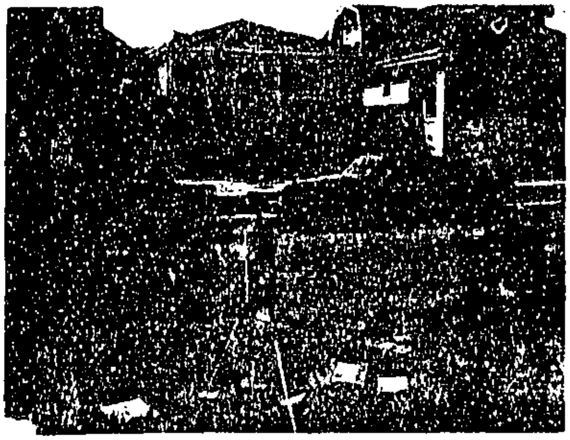


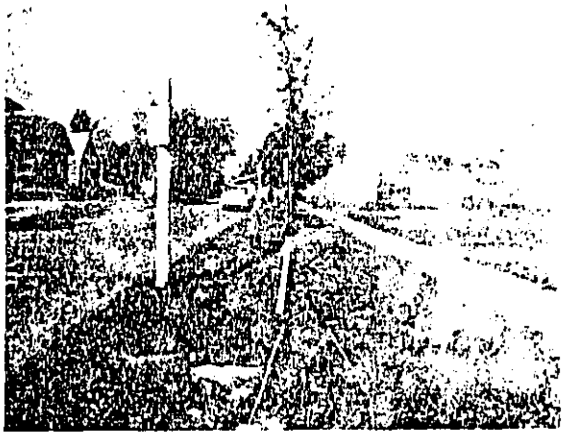
(a) Looking North, Toward Yard



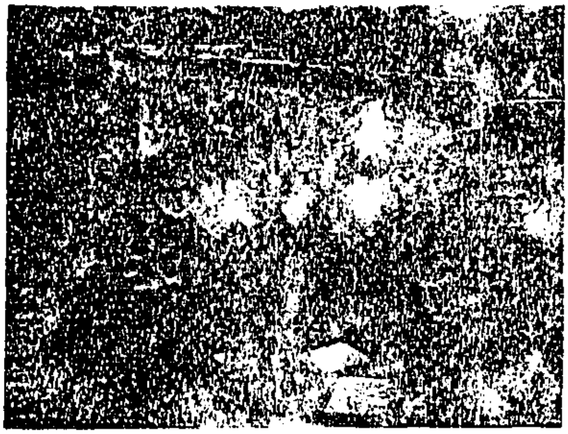
(b) Looking South, away from Yard

FIG. C.2.5. PHOTOGRAPHS OF THE WEST 29TH COMMUNITY MEASUREMENT POINT

BLACK COPY



(c) Looking West



(d) Looking East

FIG. C.2.5. (CONT.)

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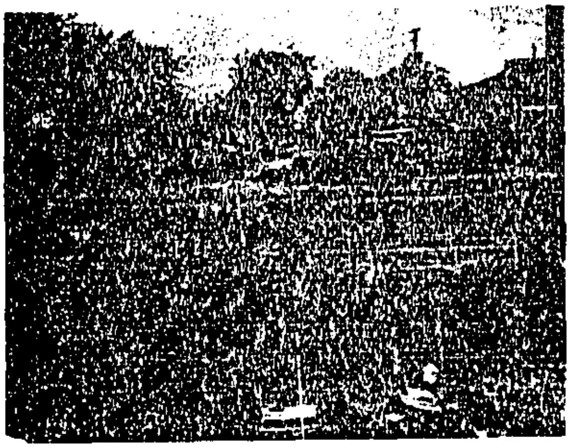
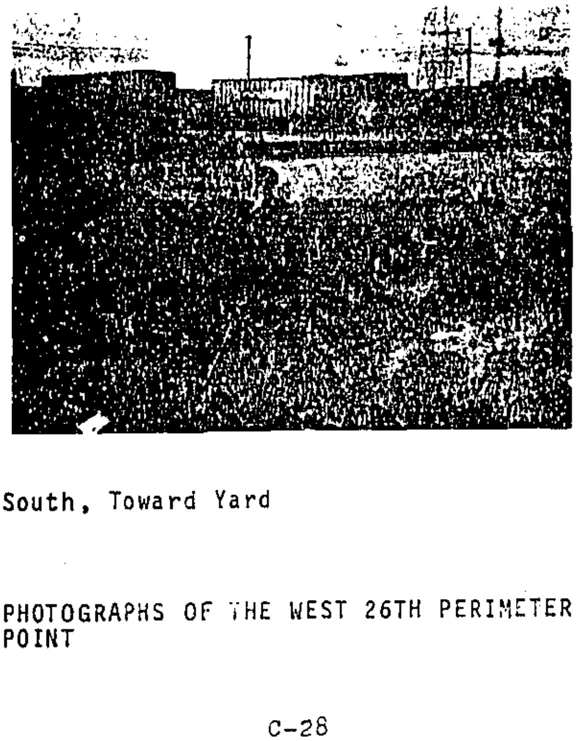


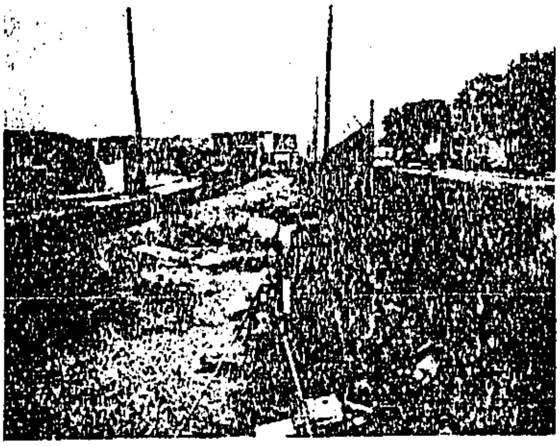
(a) Looking North, away from Yard



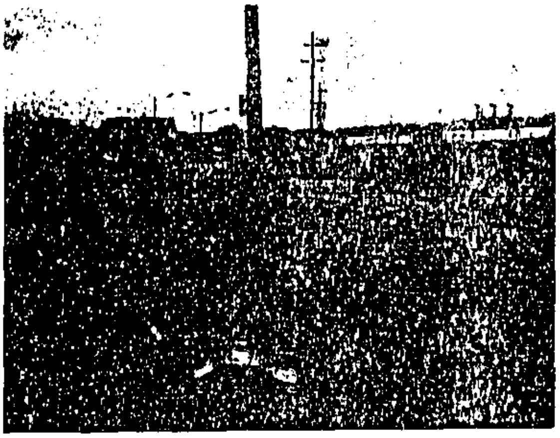
(b) Looking South, Toward Yard

FIG. C.2.6. PHOTOGRAPHS OF THE WEST 26TH PERIMETER MEASUREMENT POINT

BLACK COPY



(c) Looking West



(d) Looking East

FIG. C.2.6. (CONT.)

(a) Looking North, away from Yard

(b) Looking South, Toward Yard

FIG. C.2.7. PHOTOGRAPHS OF THE 25TH PLACE COMMUNITY MEASUREMENT POINT

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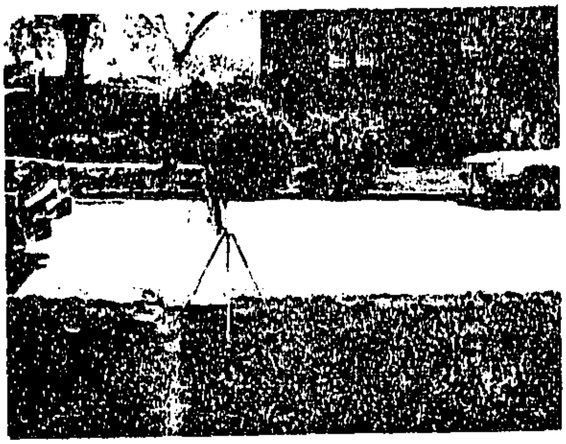
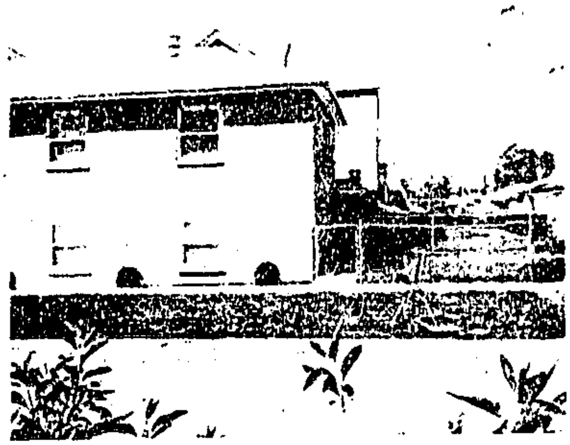


(c) Looking East



(d) Looking West

FIG. C.2.7. (CONT.)

BLACK COPY

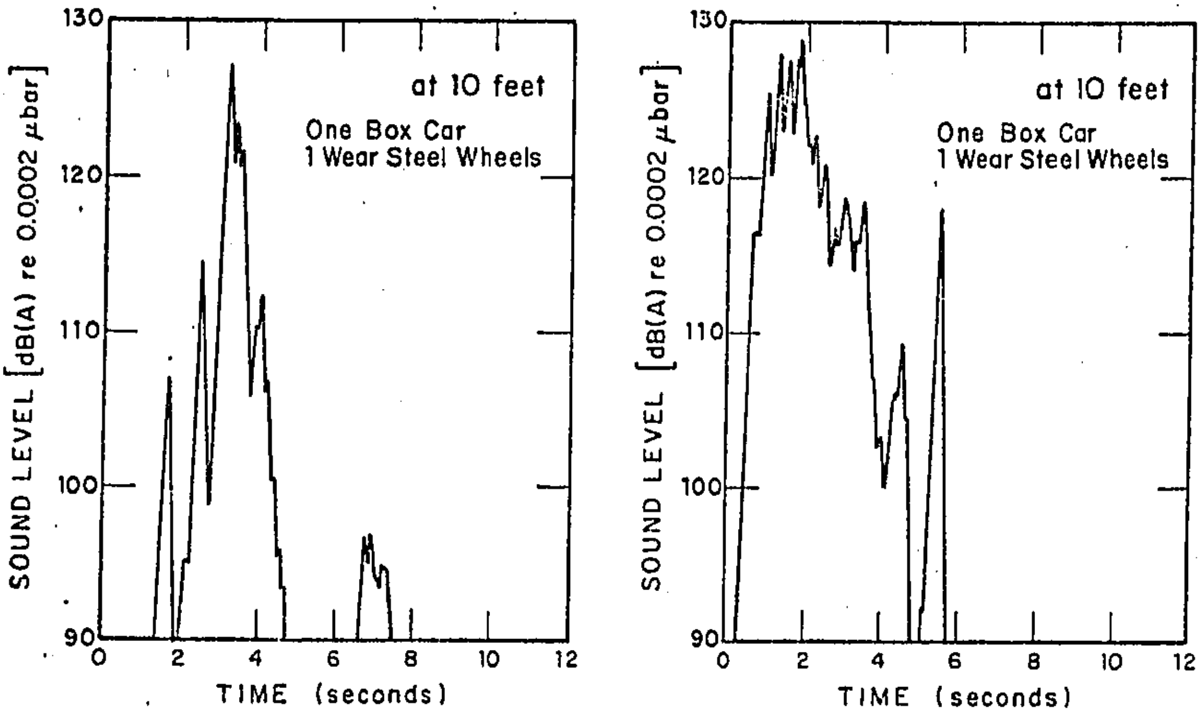


FIG. C.2.8. MEASURED RETARDER SQUEALS

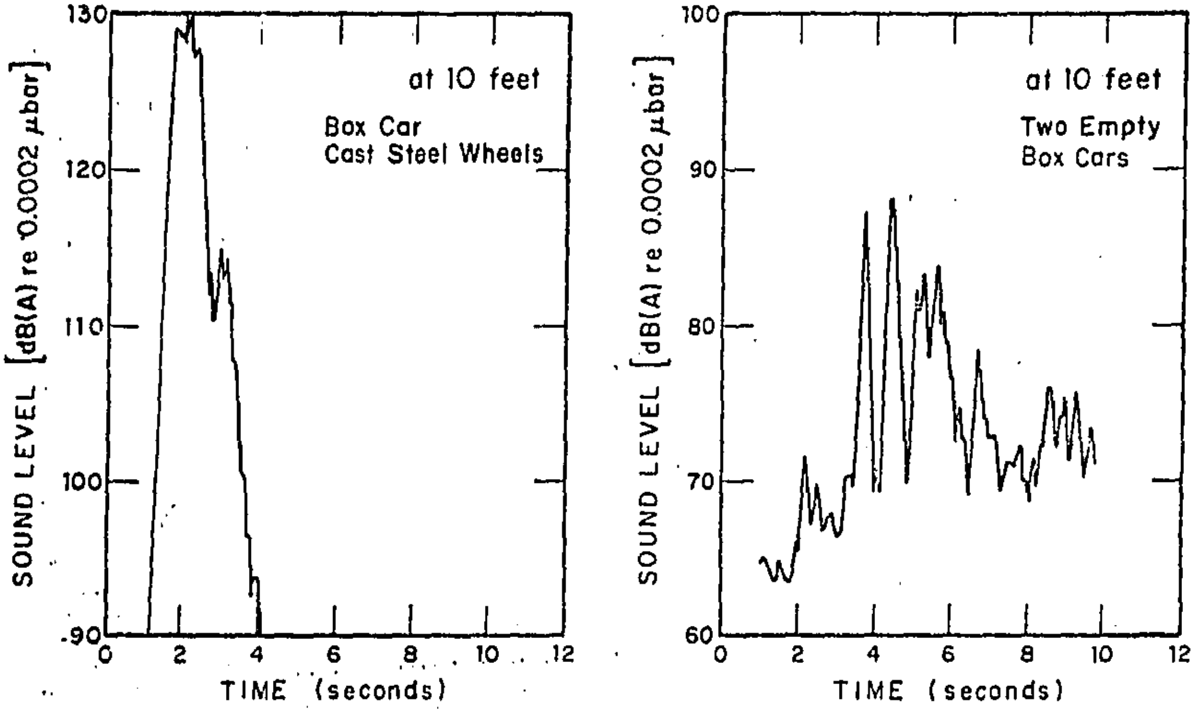

130
120
110
100
90
SOUND LEVEL [dB(A) re 0.0002 μbar]
0
2
4
6
8
10
12
TIME (seconds)
at 10 feet
Box Car
Cast Steel Wheels
100
90
80
70
60
SOUND LEVEL [dB(A) re 0.0002 μbar]
0
2
4
6
8
10
12
TIME (seconds)
at 10 feet
Two Empty
Box Cars

FIG. C.2.8. (CONT.)

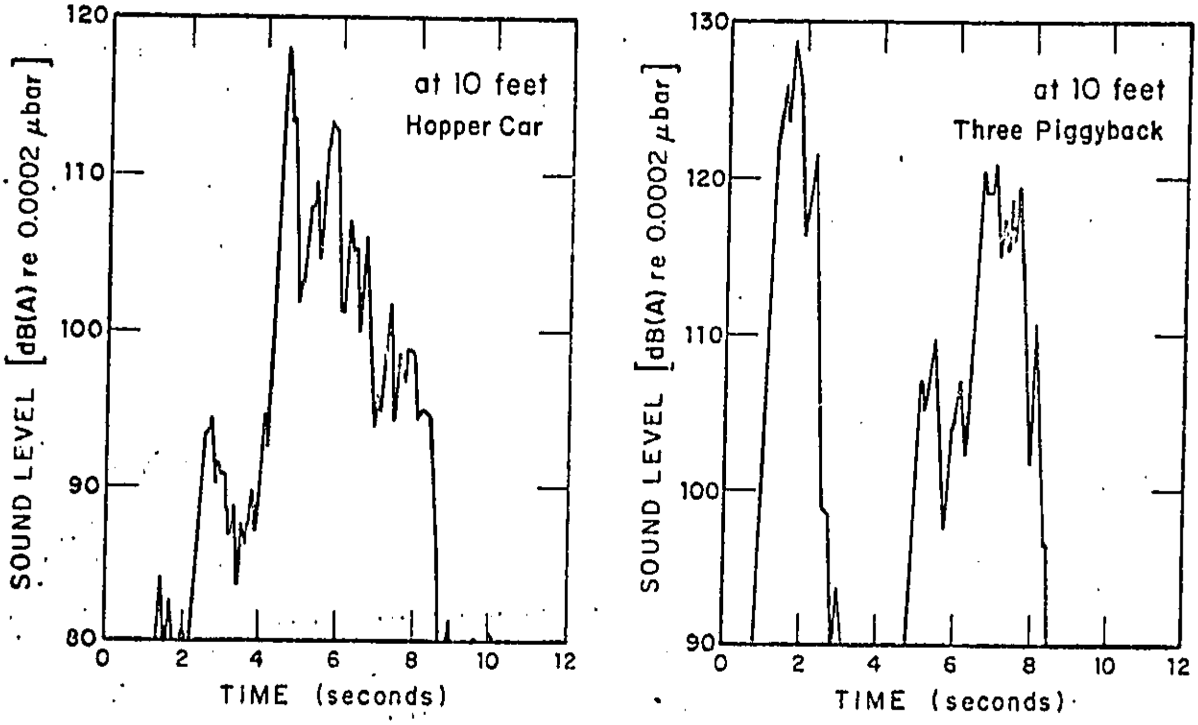

120
110
100
90
80
SOUND LEVEL [dB(A) re 0.0002 μbar]
0
2
4
6
8
10
12
TIME (seconds)
at 10 feet
Hopper Car
130
120
110
100
90
SOUND LEVEL [dB(A) re 0.0002 μbar]
0
2
4
6
8
10
12
TIME (seconds)
at 10 feet
Three Piggyback

FIG. C.2.8. (CONT.)

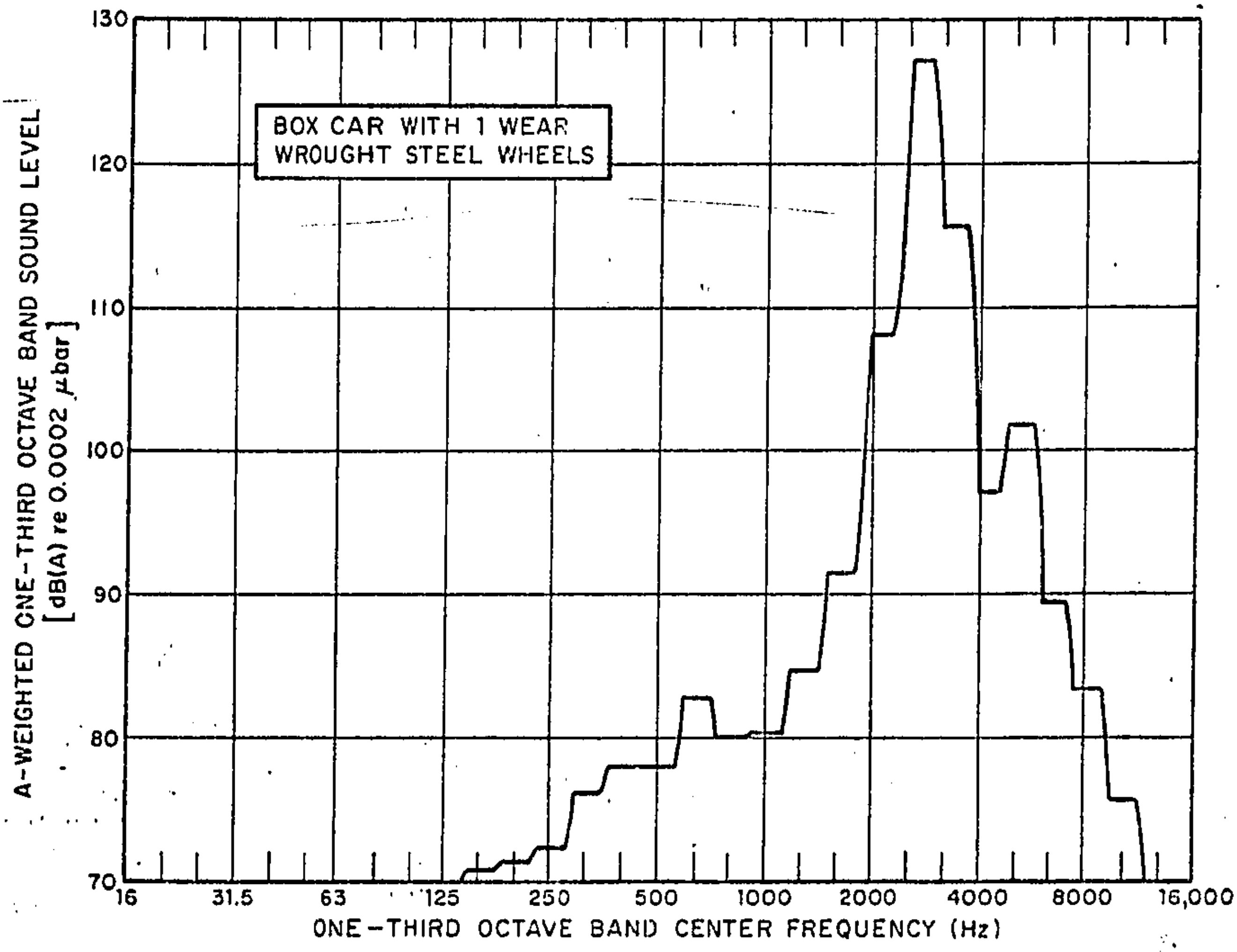


FIG. C.2.9. FREQUENCY ANALYSIS OF RETARDER SQUEALS

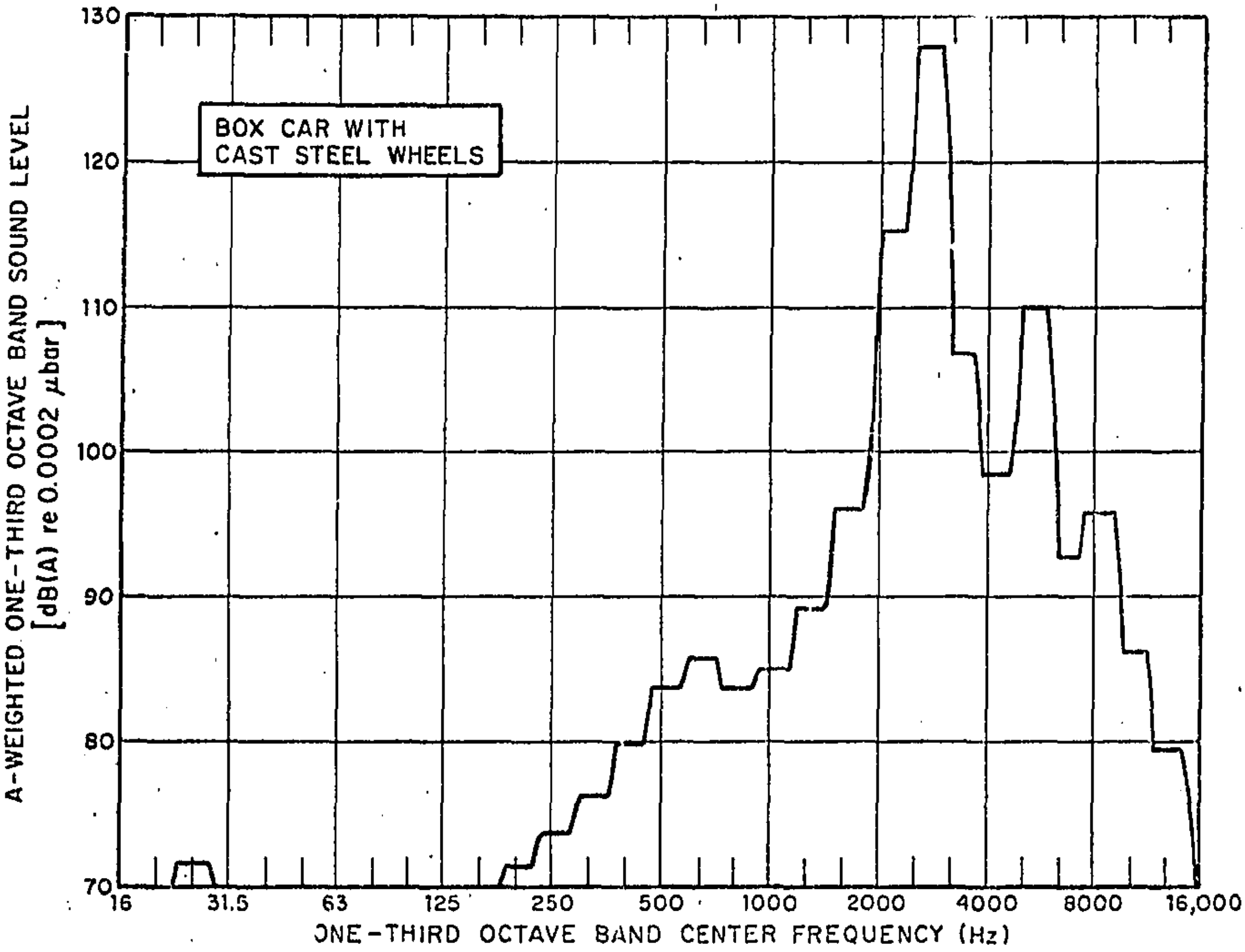

BOX CAR WITH
CAST STEEL WHEELS
A-WEIGHTED ONE-THIRD OCTAVE BAND SOUND LEVEL
[dB(A) re 0.0002 μbar]
130
120
110
100
90
80
70
16
31.5
63
125
250
500
1000
2000
4000
8000
16,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY (Hz)

FIG. C.2.9. (CONT.)

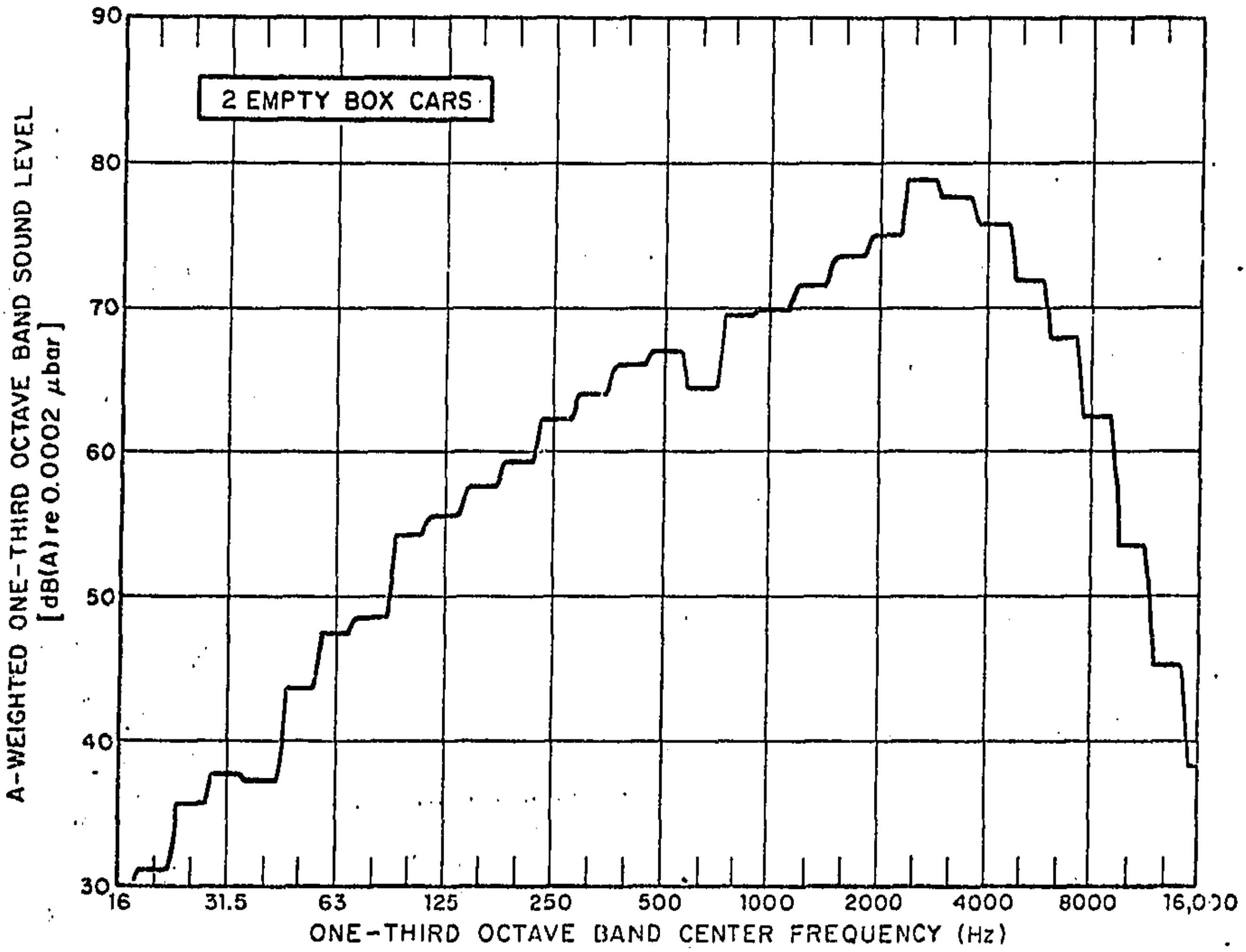

2 EMPTY BOX CARS
A-WEIGHTED ONE-THIRD OCTAVE BAND SOUND LEVEL [dB(A) re 0.0002 μbar]
90
80
70
60
50
40
30
16
31.5
63
125
250
500
1000
2000
4000
8000
16,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY (Hz)

FIG. C.2.9. (CONT.)

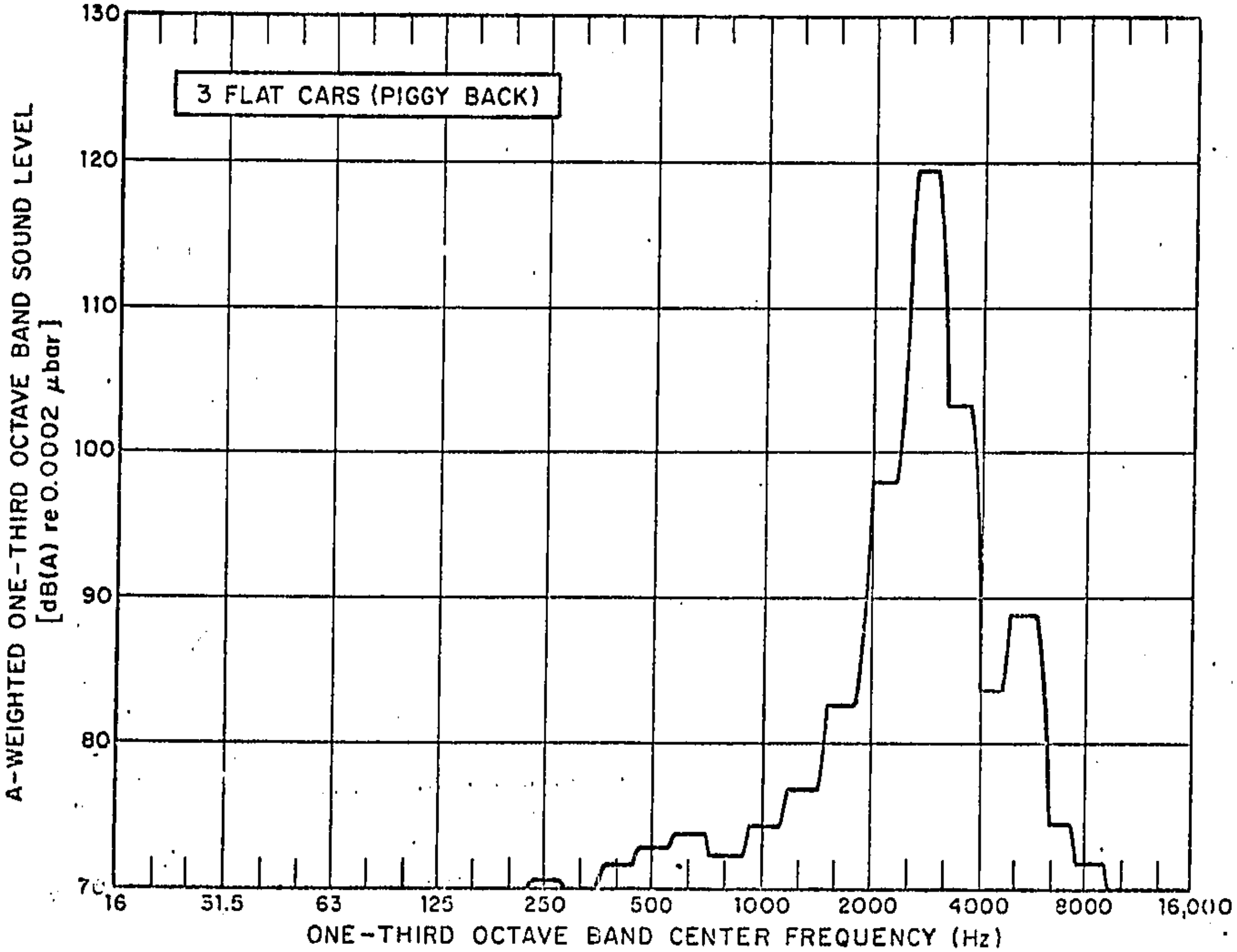

3 FLAT CARS (PIGGY BACK)
A-WEIGHTED ONE-THIRD OCTAVE BAND SOUND LEVEL [dB(A) re 0.0002 μbar]
130
120
110
100
90
80
70
16
31.5
63
125
250
500
1000
2000
4000
8000
16,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY (Hz)

FIG. C.2.9. (CONT.)

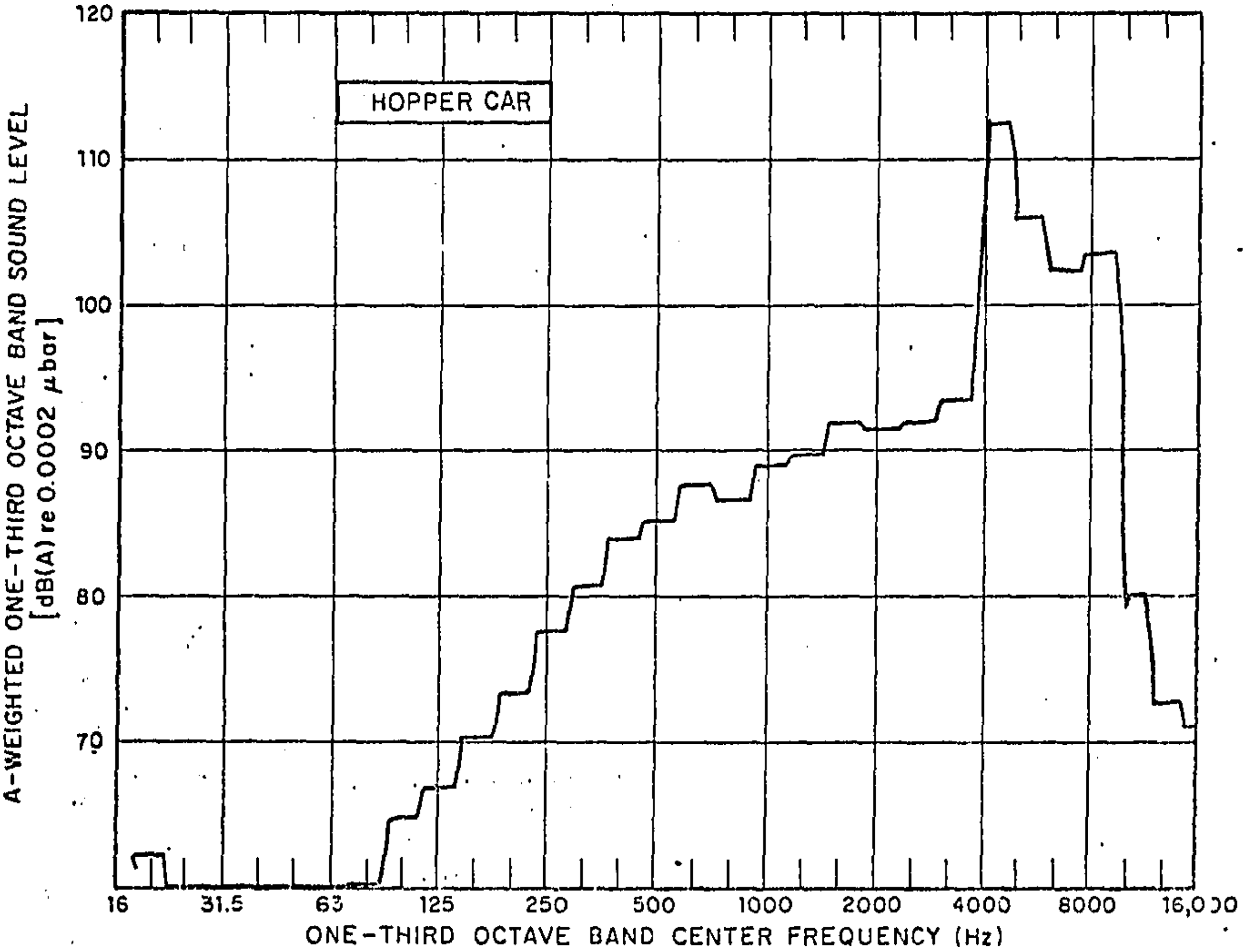

HOPPER CAR
A-WEIGHTED ONE-THIRD OCTAVE BAND SOUND LEVEL [dB(A) re 0.0002 μbar]
120
110
100
90
80
70
16
31.5
63
125
250
500
1000
2000
4000
8000
16,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY (Hz)

FIG. C.2.9. (CONT.)

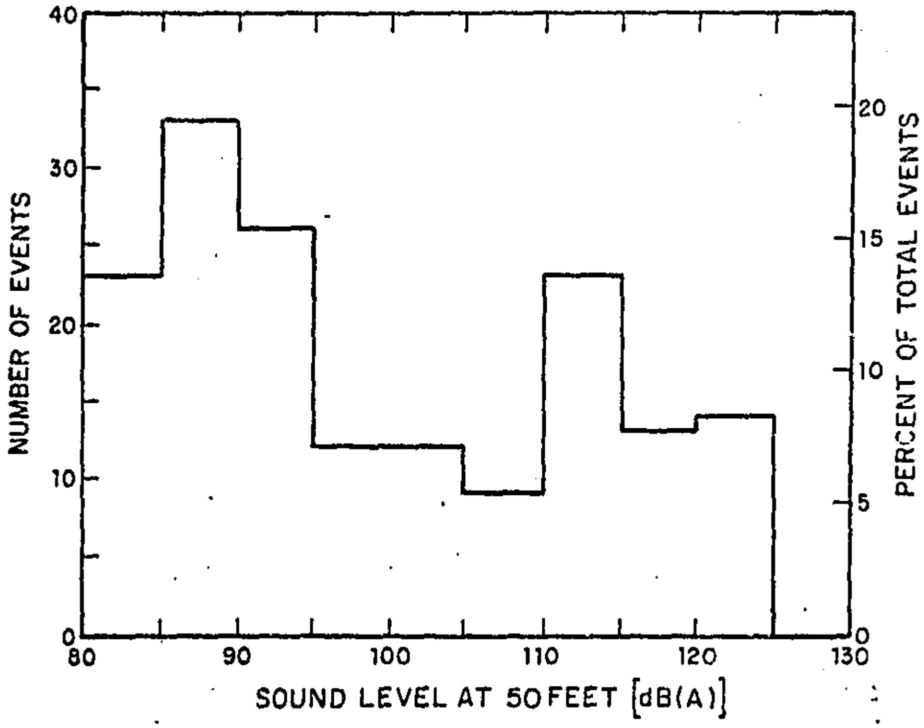


FIG. C.2.10. RETARDER SQUEAL AMPLITUDE DISTRIBUTION

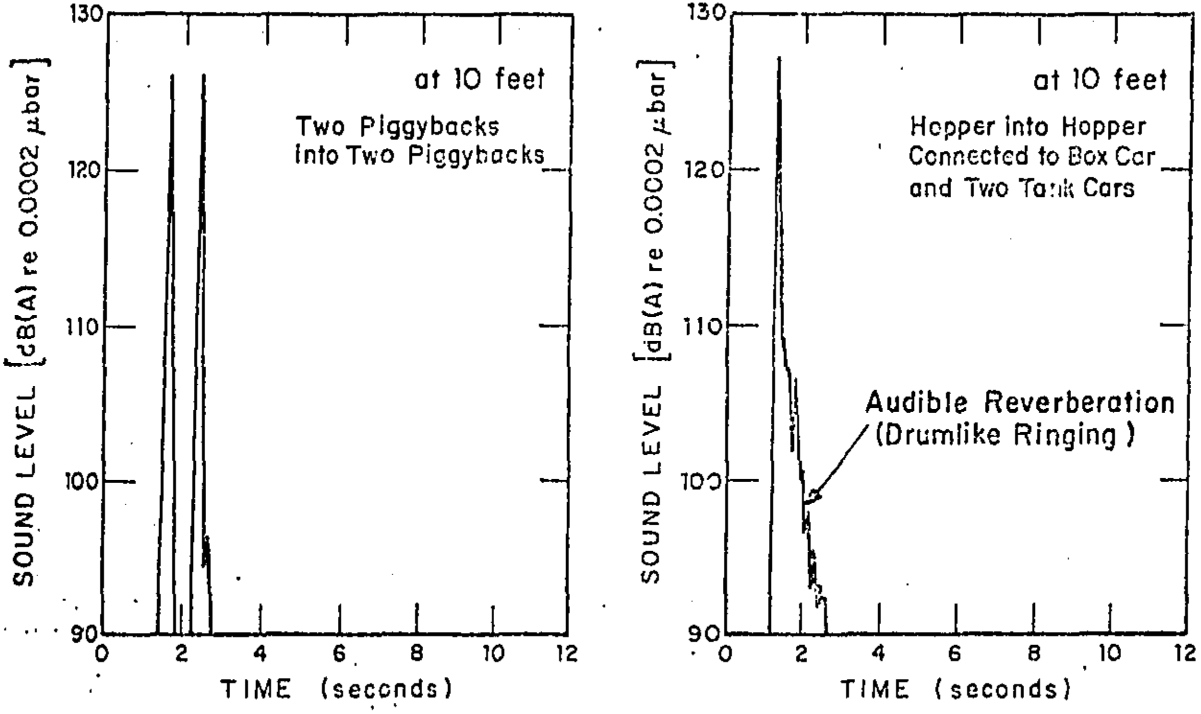


FIG. C.2.11. MEASURED CAR–CAR IMPACT NOISE

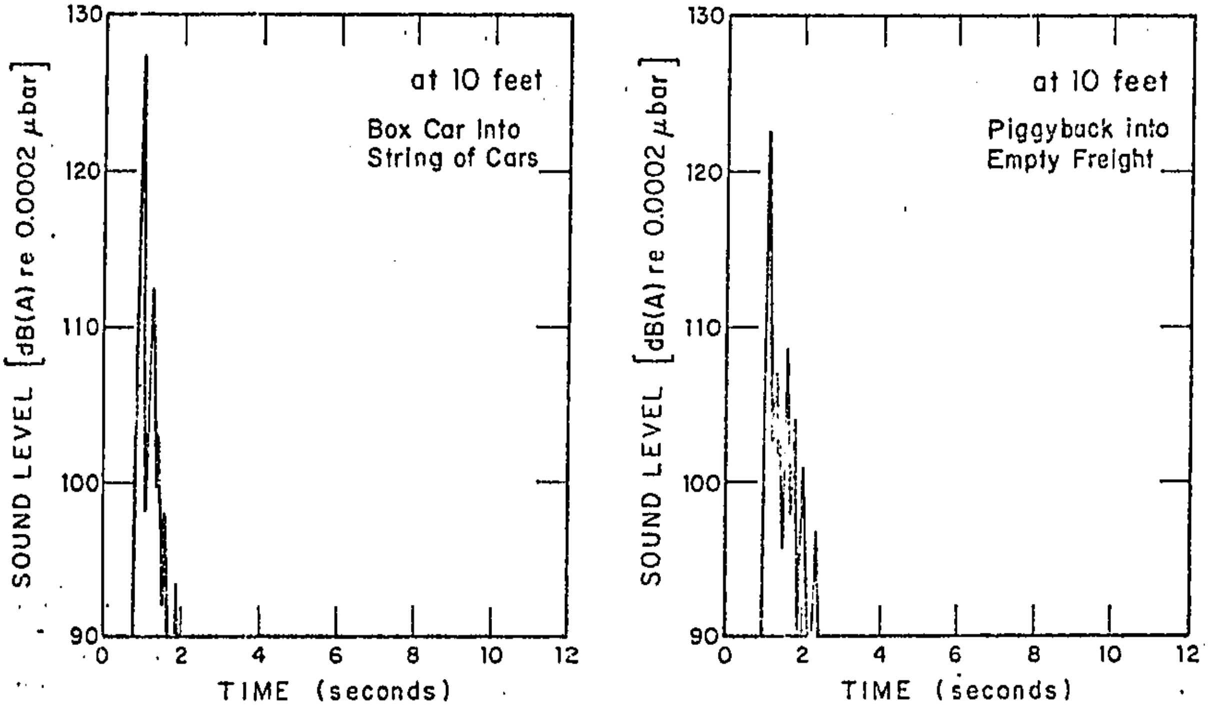


FIG. C.2.11. (CONT.)

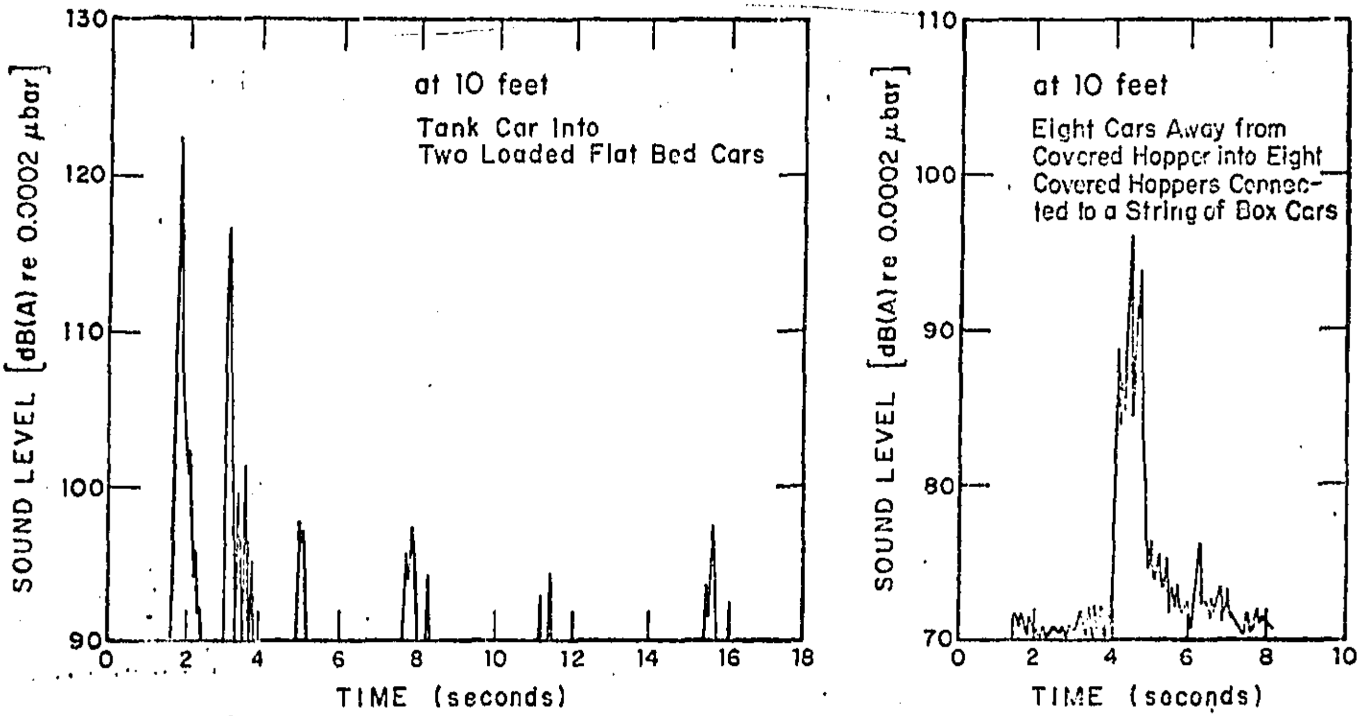


FIG. C.2.11. (CONT.)

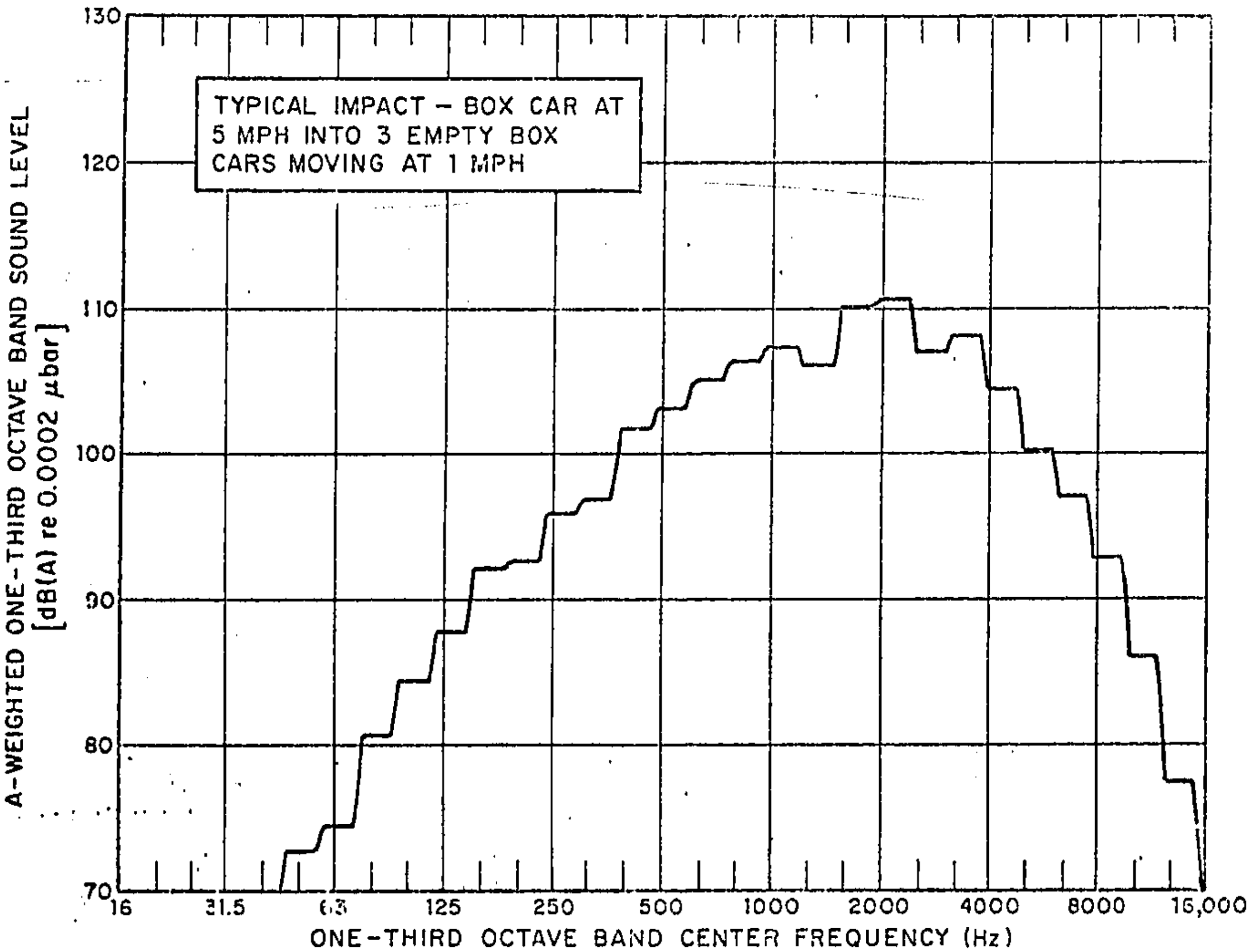


FIG. C.2.12: FREQUENCY ANALYSIS OF IMPACT NOISE

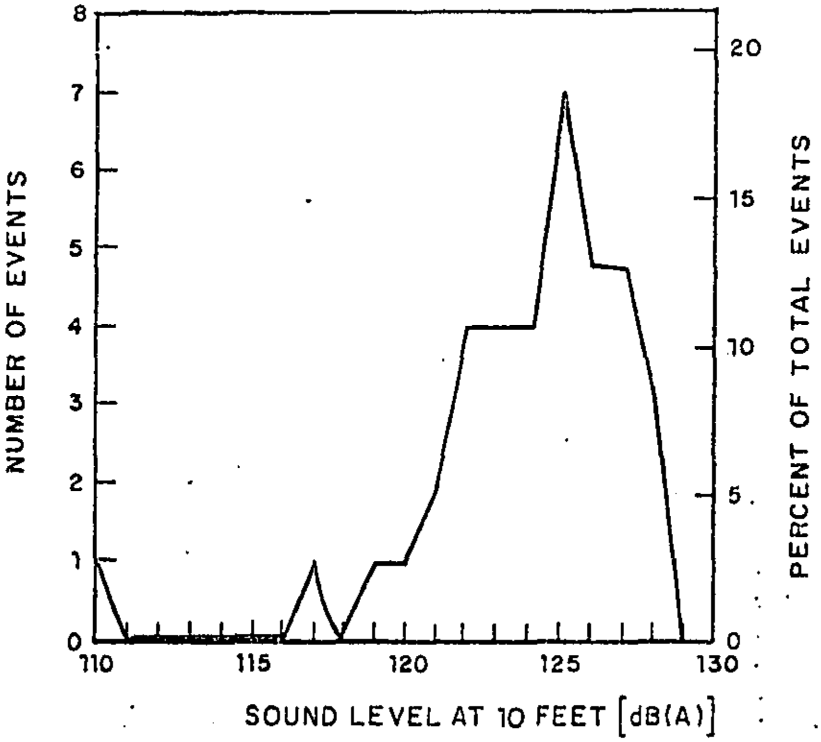


FIG. C.2.13. AMPLITUDE DISTRIBUTION OF CAR IMPACT NOISE

APPENDIX D: TIME INTEGRALS OF CUMULATIVE ACOUSTIC ENERGY

Some useful indicators of the annoyance caused by community noise are based on measurements or calculations of the energy content of noise. The energy of a sound with time-varying intensity I(t), observed from time t_1 to time t_2, is

$$E = \int_{t_1}^{t_2} I(t)dt \quad (1)$$

The average intensity over the observation period, I_{EQ}, then is

$$I_{EQ} = \frac{E}{t_1 - t_2} . \quad (2)$$

The equivalent sound power level is defined as

$$L_{EQ} = 10 \log I_{EQ}/I_{ref} \quad , \quad (3)$$

where $I_{ref} = 10^{-12}$ watts/m^2 is a standard reference intensity. The following discussion describe the calculation of E for several classes of events that are relevant to the analysis of noise from railraod operations.

D.1 Moving Point Sources

Sections 4.1 and 4.2 of this report contain discussions of the reasons for treating locomotive noise and noise from locomotive horns and whistles as though they originated at point sources.

The movement of those point sources along a railroad track can be described by Fig. D.1.1, where t is the time required for the train to travel from a point directly in front of an observer to position X at velocity V.

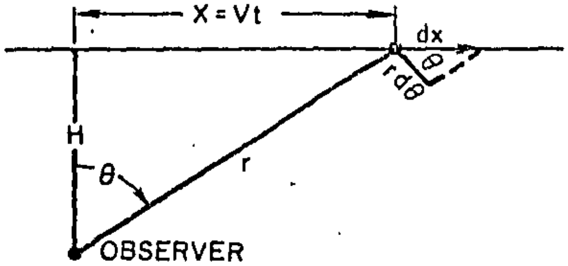


Fig. D.1.1. GEOMETRY FOR A MOVING POINT SOURCE.

The intensity of sound traveling away from a point source can be expressed as

$$I = \frac{I_0 r_0^2}{r^2} e^{-\alpha r} , \quad (4)$$

where I is the intensity a distance r from the source, I_0 is the intensity at a reference distance r_0 from the source, and α is a measure of the dissipation of the sound by mechanisms other than geometric spreading of the sound wave (see Appendix E). Substituting from Eq. 4 into Eq. 1 and noting that X = Vt yields

$$E = \frac{I_0 r_0^2}{V} \int_{-\infty}^{\infty} \frac{e^{-\alpha r}}{r^2} dx , \qquad (5)$$

where the limits on the integral are chosen so as to account for contributions occuring at the observer location as the train approach from far away and recedes a great distance.

From Fig. D.1.1,

$$r = H/\cos\theta$$

and

$$dx = \frac{r d\theta}{\cos\theta} \ , \qquad (6)$$

so that

$$E = \frac{I_0 r_0^2}{VH} \int_{-\pi/2}^{\pi/2} e^{-\frac{\alpha H}{\cos\theta}} d\theta \ . \qquad (7)$$

The values of the integral in Eq. 7 are tabulated for different values of αH in Abramowitz and Stegun (1964).

The DOT (1970) report presented a mathematical description of wheel/rail noise that was based on a line-source representation. The following mathematical technique for representing wheel/rail noise as originating at a collection of point sources is equivalent to the method presented in the DOT report. In addition, the following method provides several computational advantages, among which is a mathematically tractable method for including attenuation in excess of geometric attenuation in the calculations. The line-source representation is not mathematically tractable when excess attenuation is added.

Consider a train of length ℓ_t composed of N cars of length ℓ_c, as shown in Fig. D.1.2. The angle θ_c subtended by the car at the observer's location is.

$$\theta_c = 2 \tan^{-1} \frac{\ell_c/2}{H} . \tag{8}$$

The angle θ_t subtended by the train at the observer's location is

$$\theta_t = 2 \tan^{-1} \frac{\ell_t/2}{H} . \tag{9}$$

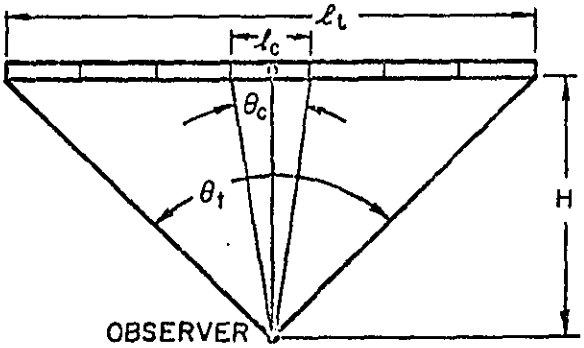


FIG. D.1.2. GEOMETRY OF POINT SOURCES OF WHEEL/RAIL NOISE.

The intensity I_c of sound at the observer's position due to a single car is related to the intensity I_t of sound at the observer's position due to the whole train by (Beranek, 1971)

$$I_c = I_t \frac{\theta_c}{\theta_t} . \tag{10}$$

One then finds that the sound levels SL of the car and train are related by

$$SL_{car} = SL_{train} + 10 \log \frac{2 \tan^{-1} \ell_c/2H}{2 \tan^{-1} \ell_t/2H} . \tag{11}$$

For most trains and for observation distances H of practical interest, $\theta_t = 2 \tan^{-1} \ell_t/2H \approx \pi$. For typical passenger cars, which are about 75 ft long, and typical freight cars which are about 55 ft long, one finds that

$$SL_{\text{passenger car}} = SL_{\text{train}} - 4\ \text{dB}\ , \tag{12}$$

and

$$SL_{\text{freight car}} = SL_{\text{train}} - 5\ \text{dB}\ . \tag{13}$$

If each car is assumed to radiate wheel/rail noise as a point source, Eq. 7 can be used to calculate the cumulative energy conveyed by the noise. The energy for one car calculated from Eq. 7 must be multiplied by the number of cars to get the total energy.

D.2 "Sawtooth" or "Spike" Noises

Sounds which rise to high levels in a short time and decay rapidly present special problems in evaluating the average acoustic energy. The procedure discussed below provides a method for approximating the energy content of such sounds.

Consider a sound which varies with time in the manner shown in Fig. D.2.1, where the sound level is assumed to rise instantaneously to level B at a time which is arbitrarily taken to be zero and is assumed to fall instantaneously from B to some insignificant value at time $2t_1$, reaching a peak at time t_1. For the sloping stright-line part of the curve,

$$SL = At + B, \tag{14}$$

where $A = SL_{max}/t_1$ (the slope of the straight line),

and $10 \log I/I_0 = At + B$

one finds that

$$I = I_0 \left(e^{.23At}\, e^{.23B}\right) \quad . \qquad (15)$$

The energy E corresponding to the spike of Fig. D.2.1 then is

$$E = 2 \int_0^{t_1} I(t)dt =$$

$$2I_0 \frac{e^{.23B}}{.23A} \left(e^{.23At_1} - 1\right) . \qquad (16)$$

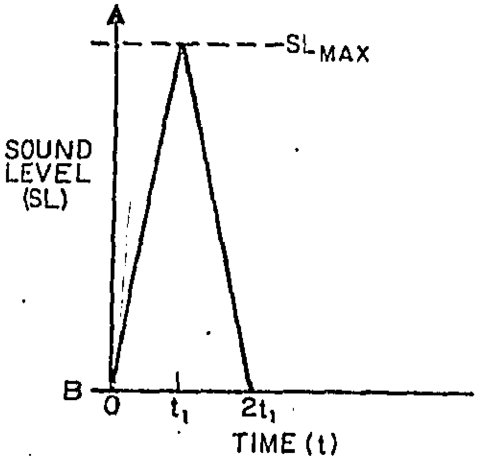


FIG. D.2.1. SPIKE PULSE SHAPE.

For most practical cases $e^{.23At_1} >> 1$, and Eq. 16 reduces to

$$E \approx 2I_0 \frac{e^{.23B}}{.23A} e^{.23At_1} \quad . \qquad (17)$$

The corresponding sound equivalent L_{EQ}, based on averaging over the duration $2t_1$ of the pulse then is found to be,

$$L_{EQ} = B + At_1 - 10 \log At_1 + 6.4 \quad . \qquad (18)$$

Since $B + At_1 = SL_{max}$, as evident from Fig. D.2.1, the above reduces to

$$L_{EQ} = SL_{max} + 6.4 - 10 \log At_1 \; . \qquad (19)$$

The following examples demonstrate the range of values typically encountered. If the sound level rises 30 dB from B in 1 sec, then

$$L_{EQ} = SL_{max} - 8 \; .$$

If L_{EQ} had been approximated by

$$L_{EQ} = SL_{max} + 10 \log \Delta t \; ,$$

where Δt corresponds to the "10 dB-down" points, the result would have been $L_{EQ} = SL_{max} - 7$, which differs from the correct value by only 1 dB. If the sound level rises 40 dB in .1 sec, then

$$L_{EQ} = SL_{max} \; .$$

APPENDIX E: EXCESS ATTENUATION OF RAILROAD NOISES

Many mechanisms cause attenuation of sound beyond that caused by geometric spreading (Beranek, 1971), including molecular absorption in the air, precipitation, barriers, ground cover, wind, and temperature and humidity gradients. The attenuation varies with location, with time of day, and with season of the year. To account for the attenuation produced by these highly variable sources, it is necessary to compile detailed records of wind, temperature, humidity, precipitation, and even cloud cover on a statistical or probabilistic basis. The following discussion is directed at a base case which includes two sources of excess attenuation that can be relied upon – atmospheric molecular absorption, and attenuation associated with variations in the physical characteristics of the atmosphere near the ground. Both of those attenuations vary with frequency (Beranek, 1971). The attenuation factors were evaluated for reference conditions of 50°F and 50% relative humidity.

Figure E.1 shows how atmospheric molecular absorption and variations of atmospheric characteristics near the ground change the shape of the locomotive noise spectrum taken from Fig. A.2.7. Notice that the high frequencies become less important as the sound travels outward from the source. The attenuation of the overall sound level (logarithmically summed octave-band sound levels) was found to be about 2 dB per thousand feet out to 4000 ft. That value was used to calculate the propagation of locomotive noise described in this report. The value for the effective overall attenuation coefficient for locomotive noise is about the same for throttle position 8 and throttle position 1.

Figure E.2 shows how the frequency-dependent attenuations change the shape of the spectrum of wheel/rail noise shown in

Fig. B.1.13. Notice that here, too, the high frequencies become less important as the sound travels outward from the source. The attenuation of the overall sound level (logarithmically summed octave-band sound levels) was about 3 dB per thousand feet out to 3000 ft. That value was used to calculate the propagation of locomotive noise described in this report.

Applying the two frequency-dependent attenuations to the spectrum for impact noise shown in Fig. C.2.12 yields an effective overall attenuation coefficient that decreases slowly from 8 dB per thousand feet beyond 500 ft from the source. That value was used in the calculations of the propagation of car-car impact noise described in this report.

Figure C.2.9 shows that retarder noise is concentrated over a narrow band of frequencies. The calculations of the propagation of retarder noise in this report included attenuation factors taken from Beranek (1971) for the appropriate frequencies.

Data reported by Embleton and Thiessen (1962) show that noise from locomotive whistles is concentrated at frequencies near 500 Hz. Data in BBN files show that noise from locomotive horns is also concentrated near 500 Hz. The calculations of the propagation of horn and whistle noise described in this report included attenuation factors taken from Beranek (1971) for 500 Hz.

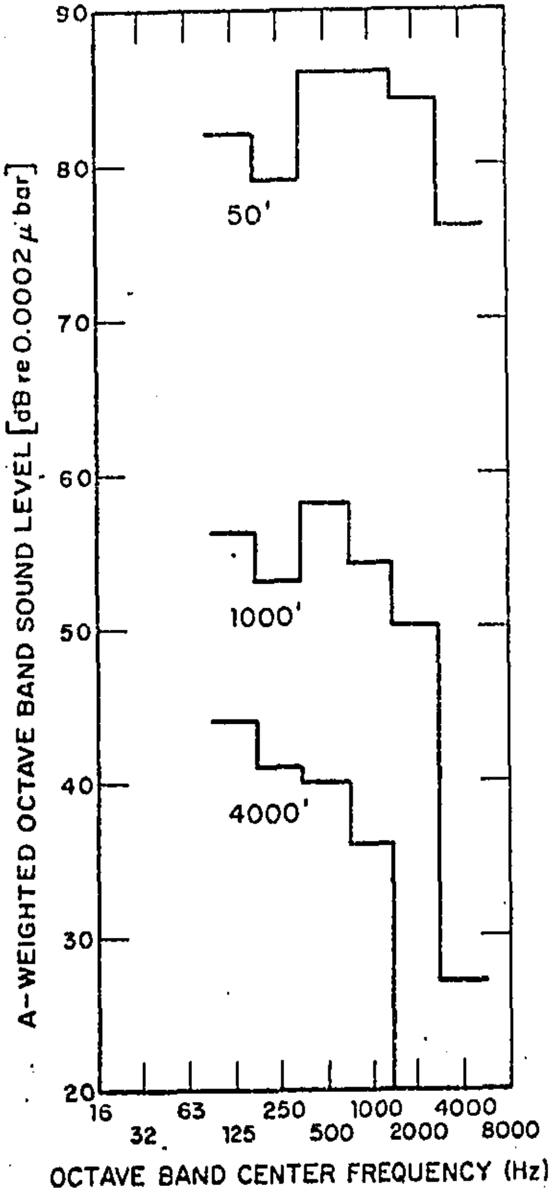


FIG. E.1. INFLUENCE OF FREQUENCY-DEPENDENT ATTENUATIONS ON LOCOMOTIVE NOISE SPECTRUM (SEE FIG. A.1.7b FOR COMPARISON)

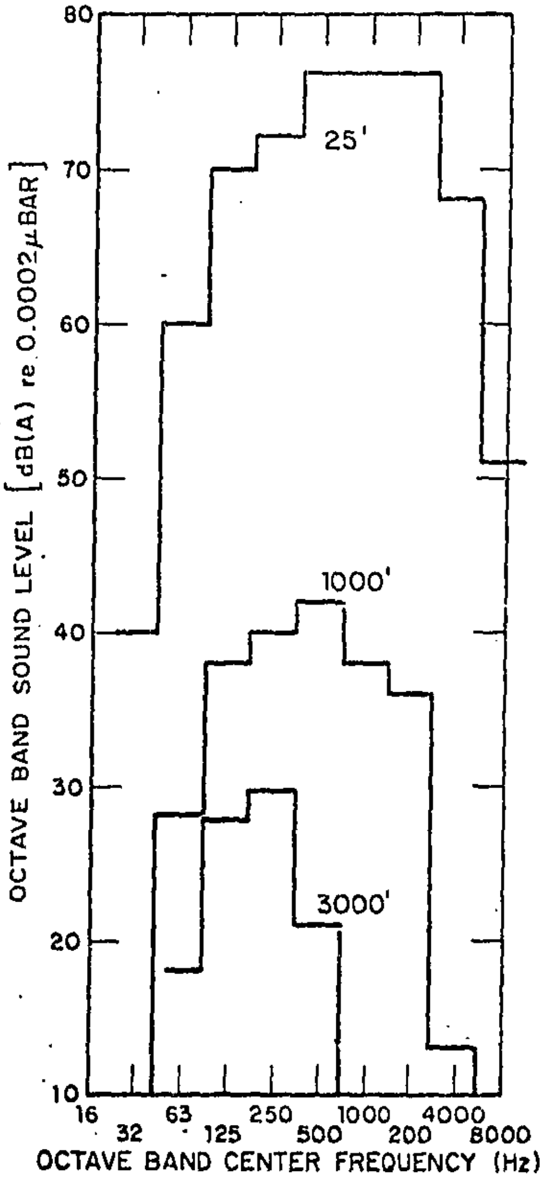


FIG. E.2. INFLUENCE OF FREQUENCY-DEPENDENT ATTENUATIONS ON WHEEL/RAIL NOISE, TRAIN NO. 6., REGION 2 (SEE FIG. B.1.13 FOR COMPARISON).

APPENDIX F

MAJOR TYPES OF DIESEL-ELECTRIC LOCOMOTIVES IN CURRENT U.S. SERVICE (1 January 1973)

Manufacturer	Type	Model	H.P.	Turbo-charged	Muffler Type	Number Sold	Years	Number In Service Class I	Number In Service Class II
eneral Motors Electro-Motive Division)	Switcher	NW2	1000	No	A	1119	39–49	721	117
		NW3,5	1000	No	A	20	39–47		
		SW1	600	No	A	660	39–56	628	107
		SW8	800	No	A	306	50–54		
		SW600	600	No	A	15	54–62		
		SW900	900	No	A	260	54–65		
		SW7	1200	No	A	493	49–51	1618	305
		SW9	1200	No	A	786	51–53		
		SW1200	1200	No	A	737	54–66		
		SW1000	1000	No	A	168$^+$	66–	168$^+$	--
		SW1500	1500	No	A	546$^+$	66–	546$^+$	--
	General Purpose Special Duty Road Switcher	GP/SD 7/7B	1500	No	B	2803	49–54	2550	133
		GP/SD 9/9B	1750	No	B	4072	54–59	3603	21
		GP/SD 18/28	1800	No	B	426	59–65	400	9
		GP 20	2000	Yes	C	335	59–62	300	7
		SD 24/24B	2400	Yes	C	224	58–63	200	6
		GP 30/30B	2250	Yes	C	946	61–63	940	--
		GP/SD/35	2500	Yes	C	1645	63–66	1642	5
		GP/SD 38	2000	No	B	1103$^+$	66–	1103$^+$	3

Manufacturer	Type	Model	H.P.	Turbo-charged	Muffler Type	Number Sold	Years	Number In Service Class I	Number In Service Class II
General Motors (Electro-Motive Division)	Road Switcher	GP 39	2300	Yes	C	87	69–70	84	3
		GP/SD 40	3000	Yes	C	2217+	66–	2213+	4
		SD 45	3600	Yes	C	1362+	65–	1362+	--
		DD 35A/35B	5000	Yes	2C	45	63–65	45	--
		DDA 40X	6600	Yes	2C	47	69–71	47	--
	Streamlined Cab/Booster Freight/Passenger	FTA/FTB	1350	No	B	1096	39–45	18	--
		F2A/F2B	1350	No	B	76	46		
		F3A/F3B	1500	No	B	1801	45–49	440	--
		F7A/F7B	1500	No	B	3982	49–53	1207	--
		F9A/F9B	1750	No	B	235	54–57	205	--
	Passenger Only (Twin Engines)	E7A/7B	2000	No	-	510	45–49	245	--
		E8A/E8B	2250	No	-	457	49–53	226	--
		E9A/E9B	2400	No	-	144	54–63	88	--
eneral Electric	Switcher	44 ton	400	No	-	334	40–56	18	95
		70 ton	500–660	Yes	-	193	46–58		
		95 ton	500–660	Yes	-	46	49–56		
	Road Switcher	U25B/C	2500	Yes	D	591	59–66	524	--
		U28B/C	2800	Yes	D	219	66	219	--
		U23B/C	2250	Yes	D	212+	68–	212+	--

Manufacturer	Type	Model	H.P.	Turbo-charged	Muffler Type	Number Sold	Years	Number In Service Class I	Number In Service Class II
General Electric	Road Switcher	U30B/C	3000	Yes	D	470^{+}	66–	470^{+}	--
		U33B/C	3300	Yes	D	497	67–	497^{+}	--
		U36B/C	3600	Yes	D	157	69–	157^{+}	--
		U50B/C	5000	Yes	2D	66	63–70	66	--
Alco	Switcher	S1/3	660	No	-	653	40–53	92	36
		S6	900	Yes	E	100	55–60		
		T6	1000	Yes	E	55	58–69	681	203
		S2/4	1000	Yes	E	2012	40–61		
	Road Switcher	RS1/RSD1	1000	Yes	E	497	41–60		
		RS2	1500	Yes	E	400	46–50	76	5
		RS2/3	1600	Yes	E	1312	50–56	564	30
		RSD4/5	1600	Yes	E	203	51–56		
		RS11/12/36	1800	Yes	D	436	56–63	348	11
		C415	1500	Yes	D	26	66–68	26	--
		RS32 C-420	2000	Yes	D	164	61–68	121	1
		RSD7/15	2400	Yes	D	102	54–60	119	--
		RSD27 C-424	2400	Yes	D	80	59–67		--
		C-425	2500	Yes	D	91	64–66	89	--
		C-628	2750	Yes	D	135	63–68	91	--

Manufacturer	Type	Model	H.P.	Turbo-charged	Muffler Type	Number Sold	Years	Number In Servic	
								Class I	Class I
[illegible]	Road Switcher	C-430/630	3000	Yes	D	93	66-68	84	--
		C-636	3600	Yes	D	34	67-68	31	--
	Streamlined Cab/Booster	FA/FB1	1500	Yes	-	581	46-50	--	--
		FA/FB/2	1600	Yes	-	491	50-56	--	--
		PA/PB1	2000	Yes	-	210	46-50	--	--
		PA/PB1/2/3	2250	Yes	-	84	50-53	--	--
ldwin ima Hamilton	Switcher	S-8	800	No		61	50-54	22	15
		DS-4-4-10	1000	Yes		433	46-51	136	46
		S-12	1200	Yes		449	51-56	190	38
	Road Switcher	RS-12	1200	Yes		46	51-56		
		DRS-H-16 RS-H16	1600	Yes		447	47-55	36	29
	Streamlined	RF16/16B	1600	Yes		160	50-53		
irbanks orse	Switcher	H10-44	1000	No		197	44-49	40	6
		H17-44	1200	No		306	50-58	164	3
	Road Switcher	H16-44/66	1600	No		364	50-63	105	--
		H24-66	2400	No		105	53-56	31	--
itcomb	Switcher		600					--	5
mouth	Switcher		300					1	3
pper Bessemer	Switcher		1200						7

anufacturer	Type	Model	H.P.	Turbo-charged	Muffler Type	Number Sold	Years	Number In Service	
								Class I	Class II
[illegible]			0					21	--
mins	Switcher		470						4
. Porter	Switcher		500						1

APPENDIX G: REVIEW OF THE USE OF AUDIBLE TRAIN MOUNTED WARNING DEVICES AT PROTECTED RAILROAD - HIGHWAY CROSSINGS

G.1 Requirements For the Use of Audible Warning Devices

The stopping distance of trains is much longer than that of motor vehicles, they are much more difficult to reaccelerate, and due to their length they often overlap more than one road intersection at a time. Therefore, trains have traditionally had the right-of-way at level crossings, while motorists are expected to look out for trains and give way. The burden is then placed upon the railroad to assist the motorist in determining when a train passage is imminent. The traditional method of doing this is to sound a whistle and/or bell and keep a headlight burning on the head ends of all trains, and to mark the crossing in some manner so as to attract the attention of approaching travelers.

Public Railroad-Highway grade crossings may be equipped with one of the following, which are classified herein into the three major headings shown:

(a) Unprotected

(1) Unilluminated stop-look-listen sign or "cross buck" at the crossing generally accompanied by striping and words painted on the road surface and passive prewarning signs in advance of the crossing.

(2) As above, plus continuous (night time) illumination of the crossing and/or the signs.

(3) As above plus flashing amber caution lights.

(4) Any of the above, plus "rumble strips" on the road surface.

(b) Protected (no gates)

This group of systems may employ combinations of the signs, lights, markings, etc. from (a) above, but is distinguished by the addition of:

(1) Flashing lights generally plus bells, which are actuated upon the approach of the trains(s) by virtue of automatic electrical signals attached to the tracks. These systems are arranged to be fail-safe, in that most internal failures cause the signal to indicate the approach of a train.

(2) Traffic lights may be used in some places, in lieu of the characteristic flashing crossing lights, but also conveying the intelligence that a train(s) is in fact in the vicinity.

(3) Watchmen, stationed at the crossing, or trainmen walking with their train, will "flag" motorists or may activate lights or other devices.

(c) Protected With Gates

In addition to active signals and advance warnings as in (b) physical barriers are automatically dropped in the motorists' path upon the approach of the train(s), often with lights attached thereto.

These gates may interrupt only the approaching highway lanes (half gates) or both lanes on each side (to discourage driving around) and may be supplemented by small pedestrian gates at walkways. However, these gates are not constructed so as to physically restrain vehicles, but are really a type of "sign", intended to assure driver attention and realization that a train is to be expected. Gates are commonly used at busy crossings where there are two or more tracks, to add a degree of protection against motorists proceeding as soon as one train has passed, when there may be one approaching on another track.

The cost of installation of crossing signals varies widely and depends greatly upon particular local circumstances. Modest installations with gates average about $30,000, and may be as high as $60,000. The annual cost of inspecting, maintaining, and repairing protected crossings is about $1,000 each, not including the cost of roadway and track work.

Complete grade separations may cost hundreds of thousands of dollars, or even millions, and while many are being constructed, the number is not statistically significant within the context of the overall problem. (When separations are installed, it is usually possible to arrange for the outright closing of a few nearby crossings, thus expanding the safety benefit of this large investment.)

The level of crossing protection installed at a particular location is determined by the hazard involved which is effected by the amount of road traffic, the number and speed of trains passing and topography. This may be determined by the judgement of local officials, the railroad managements, or both and is often established simply by a past record of accidents at a crossing in question. The investment in crossing equipment may be the responsibility of the railroad, the State or local government, the Federal government or any combination thereof. This question has been the subject of much controversy in the past, and is in a state of flux at present, with the trend being toward greater government responsibility although some railroads continue to spend large sums of their own money on new systems every year. Automatic signal system maintenance has always been the responsibility of the railroad.

Train born signals to warn motorists and pedestrians of the approach of trains are required by most States. Federal safety regulations are confined to the inspection of such devices on locomotives, to the end that - if present - they shall be suitably located and in good working order (Safety Appliance Act, 45 USCA; 49 Code of Fed. Regulation 121, 234, 236, 428, 429). The Federal government has shunned greater regulatory responsibility in this field in the past. There is a very significant

Federal research and promotional effort underway to improve grade corssing safety, however.

The State laws requiring train-born signals do not quanlify their loudness. It is common for the State laws to quatify the requirement to apply all public crossings except in municipalities, leaving the use of horms or bells in towns and cities to local discretion.

A survey of the 48 contiguous States yields the following summary of information regarding their regulations:

.. Requirements for sound signals at public crossings imposed by:

Statute	38
Public Utility Commission	1 (Calif.)
Common Law	3
Penal Code	1 (N. Y.)
None or no information	5
	48

.. Requirement at private crossing: - if view is obstructed 1

.. Signals to consist of:

Whistle or bell	24
Whistle and bell	7
Whistle	6
Bell only	2 (Fla. & R.I.)[a]

[a] Florida restriction to bells applies in incorporated areas and is accompanied by a speed restriction of 12 mph.

.. Distance at which signal is to be sounded:

Beginning at a minimum of distance (35 States varying from 660 feet in Michigan to 1500 feet in South Carolina, with an average of 1,265, the most common being 1,320 feet (80 rods).

Beginning at a maximum distance (3 States): Montana 1,320, Ohio 1,650, and Virginia 1,800 feet.

To continue until train:

Reaches crossing	35
Is entirely over crossing	3

.. Exception of some form provided for incorporated areas in at least 15 States:

California, Lowa, Indiana, Kentucky, Michigan, Minnesota, Missours, New Jersey, New York, Nevada, Utah, Virginia, Washington, Wisconsin, and Florida.

.. Exception provided at crossing with:

Gates and/or watchmen - Delaware

Flashing lights and bells - Illinois

(More is said about exceptions in a later section of this report.)

Railroad operating rules reflect the ordinances in effect in the areas through which they pass, generally encouraging the use of warning signals at the discretion of the operator to avoid accidents, but admonishing against unnecessary soundings. Specific supplementary advice is contained in Standard Rule 14, which is adopted by many carriers, requiring the sounding of signals in all situations where two or more trains are at or approaching a crossing simultaneously, due to the extra hazard consequent to the limited view and preoccupation of approaching motorists and pedestrians when they see or hear just one of the trains.

Two good examples of State requirements for the sounding of warning signals at crossings are those of California and West Virginia, attached hereto as Appendix A1, A2, and B, respectively.

Over and above statutory and regulatory requirements for the use of warning signals on trains, the judiciary and juries have tended to assume that there is a burden upon the operators of railroads to employ such devices. Numerous judgments have been made against railroads in court cases wherein the sufficiency of warnings were questioned, particularly by juries and seemingly to a relatively greater degree in California. As a result, railroads are reluctant to dispense with any ordinary action which might be construed to be a contributing factor in crossing accidents. More will be said on this topic in a later section.

In addition to requirements for warning travellers at level crossings, the State of New Jersey Public Utilities Commission has ordered that passenger carrying railroads operating in that State sound a horn or whistle prior to stopping at or passing through a passenger station on a track adjacent to a platform. (January 20, 1972, Docket 7010-525) Subsequent modifications limited this requirement to one long blast, during daylight hours, and then only when the engineer has reason to believe persons may be in the vicinity of such platforms.

G.2 Railroad - Highway Accidents

There are over 220,000 public rail highway crossings at grade in the United States, of which 22% are actively protected (Categories 2 and 3). (There are also about 150,000 private crossings.)

In 1972 there were almost 12,000 public crossing accidents, resulting in 1,260 deaths. These totals have been decreasing slowly since 1966. In 67% of these accidents the t-ain struck a motor vehicle, in 28% a motor vehicle struck trains and in 5% trains struck pedestrians or there

NOTE: Figures in this section are taken from references (4) and (5). Accident figures sometimes differ between references due to the $750 cost baseline for reporting accidents to the Federal Railroad Administration. Crossing figures may differ due to the inclusion or exclusion of private crossings.

were no trains involved. 39% of the collisions occurred at crossings provided with gates, watchman, audible and/or visible signals, while 61% were at crossings having signs which did not indicate the approach of trains (Category 1).

63% of the collisions occurred during daylight, and 37% at night. It is believed that about 67% of motor vehicle traffic flows in the daytime, 33% at night, suggesting a slightly higher crossing hazard at night (37% of the collisions with 33% of the traffic).

Automobiles constituted 73% of the motor vehicles involved, trucks 25%, motorcycles 1.3% and buses 0.3%.

When motor vehicles struck sides of trains, they usually contacted the front portion thereof, particularly during daylight; the propensity to strike elsewhere increases at night. The side of train category appear to be twice as hazardous at night, in that 53% of them occur then, with 33% of the traffic, with the peak occurring between midnight and 2 a.m. In fact, when these are deducted from the total, the train-strikes-vehicle collisions are in about equal proportion to the traffic distribution, day and night.

The propensity for accodents at actively protected crossings is also greater at night than in daylight, per unit of traffic, perhaps indicating that driver alterness is a more significant factor in these cases.

TABLE 1. SUMMARY OF PUBLIC CROSSING TYPES,
LOCATIONS AND ACCIDENTS (1970)

	URBAN	RURAL	TOTAL
GATES (category 3)	5970	2970	8940
SIGNALS (category 2)	18050	14620	32670
OTHER OR MANNED	4240	2680	6920
TOTAL ACTIVE	28260	20270	48530
(ACCIDENTS)	(3624)	(1533)	(5157)
PASSIVE (category 1)	50860	12385	17471
(ACCIDENTS)	(3827)	(3428)	(7255)
GRAND TOTAL	79120	144120	223240
(ACCIDENTS)	(7451)	(4961)	(12412)

There were 70 fatalities in 1972 at gates, and 440 total at all active crossings, somewhat less than one per 100 crossings.

Accident rates and severity are significantly higher at actively protected crossings, indicating that the greater hazards where they are installed are not fully compensated for by the increased protection. The rates are also higher in urban areas than rural, for both active and passive crossings, so that in the very areas where noise exposure is greatest, the safety situation is worst.

It could also be argued that the accidents which occurred in spite of the active protection demonstrate the ineffectiveness or waste of warnings such as train horns in such areas.

While vehicle traffic, train traffic and speed continue to increase, protection installations are also increasing, and the total number of crossings is decreasing. The 1973 Highway Act provides a total of $175 million over a three year period for crossing safety, on a 90/10 Federal share basis, or a potential total of $193 million, of which at least half is to be spent on active protection systems. Gate installations constitute about 30% of all new protection, and since such systems cost about $30,000 on the average, approximately 1,000 more gate installations should occur during this three year period, in addition to those installed at railroad initiative. The Northeast Corridor is already on its way to being totally without level crossings of any kind.

NOTE: Reports of crossing statistics vary from year to year, are often based on different reporting criteria and may be for either public and private crossings.

G.3 The Impact and Effectiveness of Locomotive Horns

Acoustical Characteristics and Noise Impact

The audibility of air horns, the predominant warning devices which are the subject of attention herein, has been investigated (1) as part of a DOT program to make crossing warning systems more effective. It was found that the horns which are presently employed are not very effective, and to be so it would be necessary to increase their loudness, "warbling" and/or the use of as many as 5 chimes (pitches) have been recommended. Obviously, since the whole purpose is to gain attention and instill a sense of imminent danger and alertness in persons located at 1/4 mile distance, such signals are bound to be disturbing - by definition.

Figure 1 shows the approximate noise pattern of an average locomotive horn. In order to increase motorist impact to a degree sufficient to be of real value, the loudness would need to be increased as much as 23 dB, resulting in a loudness of 128 dB at 100 feet. (The A and C weighted loudness of the common air horns are almost identical; no distinction is made in the literature).

Loudness at 90° from the direction of movement 5 to 10 dB less than straight ahead and it is possible that this pattern could be improved somewhat, but the loudness should be substantially maintained to at least 30^0 each side of center due to the variation in angle of approach of railroads and highways.

This problem of audible warning is shared with emergency vehicle sirens. Fire, police and rescue units have a parallel problem. With motor vehicle windows closed, in modern, acoustically well constructed vehicles, and with road noises and/or air conditioning, radios, etc. competing with the warning devices, at least 105 dB is needed outside a vehicle in order to gain the attention of most drivers. Research is underway to determine the feasibility of installing warning devices <u>inside</u> motor vehicles, which would be actuated by the approach of a train or an emergency vehicle.

In Figure 1 are shown the acoustical characteristics of the common railroad air horns, the orientation of train and vehicles in a set of relatively high speed encounters, such that the motor vehicles shown would have a reasonable stopping distance to the point and instant of train passage at a crossing. Table 2 lists the required noise levels at vehicles travelling at various speeds (exterior background noise assumed dominated by running noise of vehicle) to gain the attention of the drivers; the 50% attention column nearly corresponds to the average

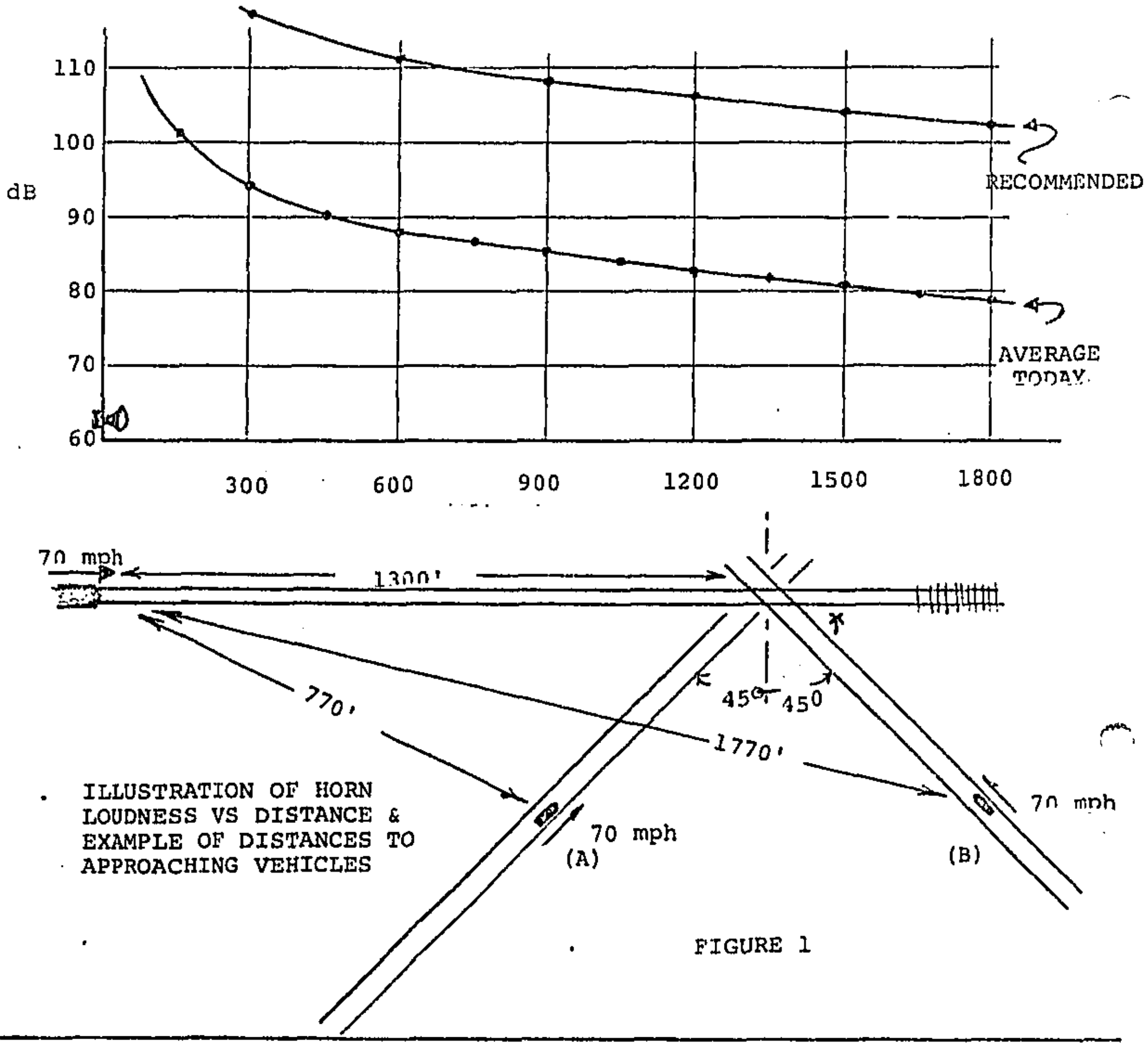


ILLUSTRATION OF HORN LOUDNESS VS DISTANCE & EXAMPLE OF DISTANCES TO APPROACHING VEHICLES

FIGURE 1

TABLE 2

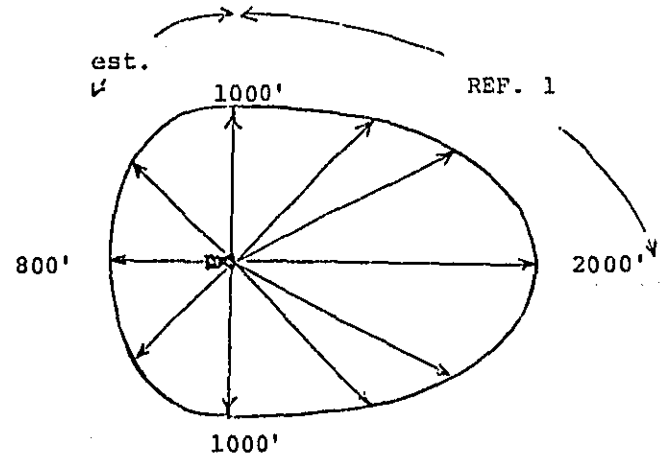
VEHICLE SPEED	dB OUTSIDE VEHICLE FOR % FOR DRIVERS TO NOTICE	
	50%	98%
≥ 35 mph	83	101
36 - 50 mph	87	105
51 - 65 mph	91	109

(SOURCE: REF 1) STANDARD DEVIATION - 6dB situation today. To alert 98% of the drivers at (B) it would be necessary to increase the sound levels by about 30 dB, resulting in a level at 100 feet abreast of the locomotive of about 130 dB.

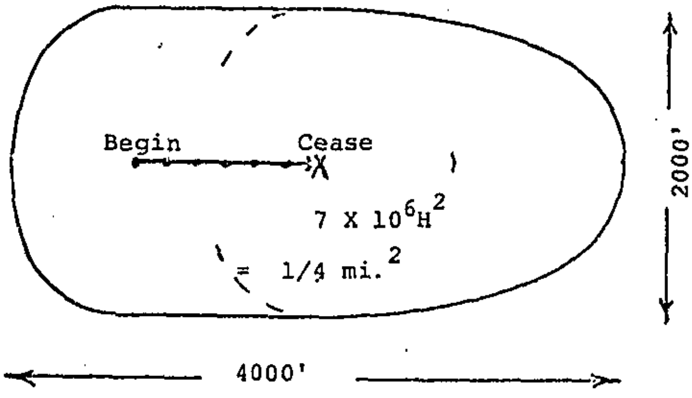
Figure 2(a) illustrates the noise pattern which characterizes most horns in use today, and Figure 2(b) depicts the areas lying within an envelope in which the noise from a horn being blown for a crossing will equal or exceed 77 dB for some period with each train passage. The 77 dB figure is chosen rather arbitrarily, largely because it corresponds to a 1,000 foot boundary adjacent to the track, which is compatible with the modest data available on residential population alongside railroads. It is also a reasonable number as regards nuisance levels of intermittent noise intrusion, being used herein merely for the purpose of approximating the scope of the impact of warning device noise.

Bolt Beranek and Newman Inc. has reviewed 202 miles of railroad route in 12 areas of 10 cities of varying overall size, selected randomly. The population within 1,000 feet of the railroads in this examination average 2,410. Therefore, in urban areas, about 600 persons are usually exposed to 77 dB from an instant up to 10 or 15 seconds each time a train passes a level crossing.

LOCOMOTIVE HORNS - AVERAGE NOISE PROPAGATION UNDER IDEAL CONDITIONS



a) 77 dB Profile



b) Area subjected to 77dB level or more
Based upon extension of profile along route

FIGURE 2

Table 3

			% of Population
1.	Unprotected	33.0 million	16
2.	Signalled	13.7	6
3.	Gated	(3.7)	(2)
	Total	46.7 million	22

(Signalled includes gated)

This would indicate that one fifth of the total population is "within hearing" of a grade crossing. In fact, the noise patterns are probably much less severe than shown here, due to topographical features, and many of the protected as well as some of the unprotected crossings are covered by restrictive ordinances, so that probably more like 10-15% of the people are exposed to the 77 dB or greater level used here for illustration (exterior to dwellings, etc.).

If the use of horns was prohibited at all actively protected crossings, 30% of these exposures would be avoided. If such a restriction was confined to crossing with gates, 8% of the exposures would be avoided. These abatement measures would be noticeable to about 3% or 1% of the population, respectively, allowing for attenuation locally and background noise and the fact that many crossings are already covered by such rules.

Assuming that the use of signals and gates corresponds to the highest hazard levels or volume classes as depicted by the Department of Transportation, the number of daily train and vehicle passages at the crossings in question has been estimated as shown in Table 4.

Table 4

	Daily Trains	Daily Vehicles
Total over signalled crossings	950,000	160,000,000
Average per signalled crossing	20	3,300
Total over gated crossings	200,000	70,000,000
Average per grated crossing	22	7,800

If the average train sounds its horn over a period of 12 seconds, the average citizen within 1,000 feet will experience the noise at 77 dB or more for an average of 8 seconds. This will occur at gated crossings 22 times per day (0.2% of the time), and at all signalled crossings, 20 times per day.

People residing within hearing of grade crossings are generally conditioned to the sound, which tonewise is not particularly disturbing. The most common casual notice of the use of horns at crossings is expressed by persons staying at motels, which are not infrequently located on highways which parallel railroads and are near road crossings. Being otherwise unaccustomed to the sound, it is quite noticeable, particularly at night.

Warning Effectiveness of Horns

As noted above, at present only about half of all motorists can notice the sound of a train horn when they are driving and their windows are closed, even under ideal conditions. And the alerting capability - even if the horn is noticeable - is still less. It is impossible to determine how many accidents have been prevented by the routine sounding of horns, although it is apparent from the experience of train drivers that many accidents have been averted by the ad hoc sounding of horns, while an even greater number have occurred in spite of it. However, these comments are directed to all crossings, passive (unprotected) as well as active (protected). It is unlikely that either routine or ad hoc use of horns at crossings where lights are flashing and bells are ringing at the crossing significantly improves ordinary driver attention, particularly where gates are lowered as well. On the other hand, some drivers and most pedestrians can hear the horn when it is sounded. Also, in those occasional incidents where a vehicle is stalled on a crossing the horn may serve to divert people from continued efforts to move their vehicle and to depart forthwith on foot. But in the latter case, sounding on a routine basis is probably not necessary.

Attached hereto as Appendices C, D, and E are (abridged) reports on three rather typical grade crossing accidents wherein the accidents occurred in spite of crossing signals and the sounding of warnings by the train. These are selected somewhat randomly, to illustrate by example a kind of crossing accident which is all too common.

In another research study on driver information systems for grade crossings (2) five warning systems were investigated in detail, but, illustrating the common resignation with regard to the effectiveness as well as undesirability of train carried audible devices, they were not even included in the study.

G.4 Prohibition against the use of audible devices

It is already quite common for the routine sounding of horns or whistles to be prohibited, except in emergencies. It is also common for these prohibitions not to be enforced. A careful search for cases where such prohibitions appeared to, or were claimed to contribute to an accident has not yielded evidence of a single such situation.

Among the localities which restrict the use of horns are those listed in Table 5.

Table 5. Some Localities with Restrictions

	Notes
The State of Florida	(2)
The State of Illinois	(1)
The State of Massachusetts	
Chicago, Illinois	(1) (2) (3)
Houston, Texas	(1) (2)
Minneapolis, Minnesota	
Buffalo, New York	(1) (2)
Philadelphia, Pennsylvania	
Knoxville, Tennessee	(1) (2)
Durham, North Carolina	(2)
Mason City, Iowa	(3)
Warren Pennsylvania	
Elkhart, Indiana	
Toledo, Ohio	
Columbus, Ohio	
Akron, Ohio	
Lynchburg, Virginia	(1) (2)
San Bernadino, California	(1)
South Holland, Illinois	
Elmhurst, Illinois	
Lockport, N.Y.	
Rochester, N.Y.	

(1) Contacted local authorities in course of this study.

(2) Specific Information contained in Appendix F.

(3) Not enforced.

The 15 states where requirements to use horns are excepted, but not necessarily prohibited, in incorporated areas are:

Table 6.

California*
Florida
Iowa*
Kansas
Kentucky*
Michigan*
Minnesota
New Jersey
New York*
Nevada*
Utah
Virginia*
Washington
Wisconsin

(*also have local-option provision)

In 4 additional states there is a local option provision, allowing cities and towns to relieve requirements:

Table 7.

Illinois
Indiana
North Carolina
West Virginia

Two states permit silent running at crossings with certain protection systems:

.. Delaware: warning requirements do not apply when crossing is protected by watchman or gates.

.. Illinois: requirements do not apply when crossing is protected by automatic signals (with or without gates).

The most comprehensive Noise Control Regulation thus far drafted anywhere is that of the State of Illinois. As it stands, its property line limitations would affect the use of audible crossing warning devices except that its Rule 208, Exceptions, states: "Rules 202 through 207 inclusive shall not apply to sound emitted from emergency warning devices and unregulated safety relief valves."

Thus, it can be seen that there is considerable precedent for placing constraints upon the use of audible warnings, with no apparent adverse effects. However, they are not uniformly enforced, and where enforced, the carrier generally receives written instructions from the constraining authority, and is nevertheless impowered to sound warnings "in emergencies"..."in the event of impending accident"... etc.

G.5 Judicial Background

Tort litigation constitutes the bulk of the legal or judicial history of grade crossing safety responsibility. Abstracts of 2500 cases throughout the United States during the period 1946 to 1966 have been surveyed (3), checking into 300 possibly related to the question at hand.

In addition, 5 cases were cited by a cooperating railroad as illustrative of the railroad liability question. One of these was found to be inapplicable to the question at hand, three were decided in favor of the railroad. In the other, a jury found for the plaintiff, although a whistle had in fact been sounded. Of these, 21 appeared to be somewhat related and the case records were reviewed. Nothing was unearthed which would appear to deter Federal or local constraints on audible traincarried devices at protected crossings.

Several themes are woven through the opinions rendered in the many cases on record. These are certainly not uniformly respected, but they are sufficiently common as to be noticeable:

.. Safety provisions, including warnings, should be compensurate with the specifics of local conditions.

.. The railroad is expected to give "adequate and timely" warning of the approach of a train. The railroad's case is often intended to show that their warning could have been heard by an attentive motorist.

.. To be cause for placing liability, an omission on the part of the carrier generally must be shown to have contributed to the event in question.

.. Motorists are generally expected to be cautious at crossings, to the extent even of stopping or look "and listen".

.. Contributory negligence on the part of a motorist is generally taken into account.

The fact remains, however, that courts, especially juries, have extracted severe payments from railroads, seeming usually to give plaintiffs the benefit of all doubt. For this reason, railroad companies are understandably at pains to make any changes which could conceivably be construed as a reduction in safety precaution (or increase in hazard). Also, the employees charged with operating trains are usually subject to prosecution under criminal law if negligence and/or violation of a statute might be involved, and are thus inclined to err in the direction of sounding their warning devices, not to mention their sincere personal desire to avoid injury to even the negligent public, as well as themselves. (Collision between trains and large trucks, especially those carrying hazardous materials, are very dangerous to the occupants of the train.) A possible fine for violation of a noise ordinance is not nearly as imposing a threat as the liablility, criminal action and conscience which accompany the threat of collision.

G.6 Summary

One of the railroad noise sources which has been commented upon in the course of interstate rail carrier regulatory development by the Environmental Protection Agency (EPA), Office of Noise Abatement and Control, is that of railroad train horns which are sounded routinely at grade crossings. It has been suggested that such sounding be prohibited in cases where automatic, active protection is in operation at the crossing itself, particularly where this protection includes gates.

This study found that neither the safety hazard involved in such a constraint, nor the noise intrusion without constraint, is very significant. Neither does it appear likely that the EPA would be exposed to serious legal liabilities by virtue of a carefully constructed regulation constraining the routine use of horns at certain well protected crossings. Such restrictions are presently quite common on a local basis.

However, it remains that the routine sounding of horns might be contributing to the prevention of some accidents, although this is purely speculative. Certainly, a small segment of the population is exposed to serious noise intrusion thereby and a reduction in their welfare, particularly at night. But it is doubtful that anyone's health is thus impaired, and it would be imprudent to single out and restrict night time use of horns, since the crossing hazard with regard to driver behavior is, if anything, worse at night.

In view of the questionable value of train horns for warning highway drivers, particularly at locations having active crossing signals, it may be appropriate to encourage the abolition of routine use of horns at crossings so equipped, particularly but not necessarily only those with gates. The circumstances which determine hazard levels as well as noise intrusion vary widely and are peculiar to local circumstances. It is therefore concluded that regulation of railroad warning be best left to the option of local authorities at this time, recommending thereto that serious consideration be given to restrictions upon the routine sounding of train horns at protected crossings.

REFERENCES

1. The Visibility and Audibility of Trains Approaching Rail-Highway Grade Crossings; J. P. Amelius, N. Korobow; NTIS-PB-202668.
2. Driver Information Systems for Highway-Railway Grade Crossings; K. W. Heathington, T. Urbanik.
3. American Digest System, 6th and 7th Dicennial Digests.
4. Rail Highway Grade Crossing Accidents from the Year 1972, Department of Transportation, Federal Railroad Administration.
5. Report to Congress on Railroad-Highway Safety, No. II, Department of Transportation, FRA/FHWA.

ENCLOSURE A

Public Utilities Code Annotated of the
  State of California
Adopted May 31, 1951
Page 784

ARTICLE 8
CRIMES

Collateral References

§ 7678. Omission to sound bell or whistle. Every person in charge of a locomotive-engine who, before crossing any traveled public way, omits to cause a bell to ring or steam whistle, air siren, or air whistle to sound at the distance of at least 80 rods from the crossing, and up to it, is guilty of a misdemeanor.

Legislative History

Enacted 1951. Based on former Pen C § 390, as amended by Stats 1949 ch 391 § 1 p 733, without substantial change.

Collateral References

Cal Jur 2d Railroads § 44.
McKinney's Cal Dig Railroads § 71.
Am Jur Railroads §§ 357 et seq.

PUBLIC UTILITIES CODE, STATE OF CALIFORNIA
(Abridged)

7604. A bell, of at least 20 pounds weight, shall be placed on each locomotive engine, and shall be rung at a distance of at least 80 rods from the place where the railroad crosses any street, road or highway, and be kept ringing until <u>it</u> has crossed the street, road, or highway; <u>or</u> a steam whistle, air siren, or an air whistle shall be attached, and be sounded <u>except in cities</u>, at the like distance; etc.

ENCLOSURE B

THE WEST VIRGINIA CODE

(Abridged)

§ 31-2-8. Warning of approach of train at crossings; crossing railroad tracks.

A bell or steam whistle shall be placed on each locomotive engine, which shall be rung or whistled by the engineer or fireman, at a distance of at least sixty rods from the place where the railroad crosses any public street or highway, and be kept ringing or whistling for a time sufficient to give due notice of the approach of such train before such street or highway is reached, and any failure so to do is a misdemeanor punishable by a fine of not exceeding one hundred dollars; and the corporation owning or operating the railroad shall be liable to any party injured for all damages sustained by reason of such neglect.

- I. Scope of Statute as to Warnings.
  - A. General Consideration.
  - B. Does Not Apply to Trespassers.
  - C. Does Not Apply to Employees.
- II. Failure to Give Warnings as Negligence: Contributory Negligence.
- III. Evidence.

I. SCOPE OF STATUTE AS TO WARNINGS.

A. General Consideration.

Michie's Jurisprudence.—For full treatment of accidents at crossings, see 15 M.J., Railroads, §§ 65-101. As to duty to give signal by bell or whistle, see 15 M.J., Railroads, §§ 81-83.

ALR references. — Railroad company's negligence in respect to maintaining flagman at crossing, 16 ALR 1273; 71 ALR 1160.

Duty of railroad company to maintain flagman at crossing, 24 ALR2d 1161.

Admissibility of evidence of train speed prior to grade-crossing accident, and competency of witness to testify thereto, [illegible]

The common-law requirement as to signals is fully as exacting as the statutory duty. What the notice and warning to the public shall be depends, under the common law, upon the circumstances of each case; but some adequate methods of apprising travelers of the crossing must be practiced. Niland v. Monongahela & West Penn Pub. Serv. Co., 106 W. Va. 528, 147 S.E. 478 (1928).

Both bell and whistle are not required without statute. — There is no absolute requirement upon a railroad company to blow a whistle and ring a bell at a crossing unless made so by statute. Niland v. Monongahela & West Penn Pub. Serv. Co., 106 W. Va. 528, 147 S.E. 478 (1928).

The methods of apprising travelers of a crossing almost universally adopted are by the ringing of a bell or the sounding of a whistle, but in order to make both obligatory, the use of both must be required by a statute. Niland v. Monongahela & West Penn Pub. Serv. Co., 106 W. Va. 528, 147 S.E. 478 (1928).

Provisions of section are minimum requirements.—The provisions of this section as to warning signals are of broad application and are minimum requirements, and in every case the compliance with this statute, plus the presence of an efficiently operating crossing [illegible] not (apart from the question of contributory negligence of the plaintiff) constitute an ironclad defense to the railroad, under all circumstances. Baltimore & O.R.R. v. Deneen, 161 F.2d 674 (4th Cir. 1947).

Travelers have the right to assume that trains will give the usual signals at crossings. Morris v. Baltimore & O.R.R., 107 W. Va. 97, 147 S.E. 547 (1929).

But railroad only owes duty to signal as required by statute.—The driver of an automobile on a public crossing is an invitee, and the railway company is bound only to use reasonable care not to collide with the automobile, and owes only the duty to give the signals provided by statute. Chesapeake & O. Ry. v. Hartwell, 142 W. Va. 318, 95 S.E.2d 462 (1956).

As this section is intended to protect [illegible] on highway.—The duty imposed [illegible] to sound a bell or whistle when [illegible] a public crossing does not [illegible] railroad company to give such [illegible] but to persons who [illegible] use the railroad tracks as parts of the highway. Jones v. Virginian

II. FAILURE TO GIVE WARNINGS AS NEGLIGENCE; CONTRIBUTORY NEGLIGENCE.

Violation of section is negligence.—The failure to give proper signals of the approach of a train to a railroad crossing as required by this section would constitute negligence on the part of a defendant railroad. Cavendish v. Chesapeake & O. Ry., 95 W. Va. 490, 121 S.E. 498 (1924).

But does not impose liability unless it proximately causes injury.—Liability for injury to baby of 13 months could not be based on failure to give signals since the failure was not the proximate cause of the injury. Virginian Ry. v. Armentrout, 158 F.2d 358 (4th Cir. 1946).

Failure to ring the bell or blow the whistle at crossings, though required by law, will not render the company liable, unless that be the proximate cause of the injury. Beyel v. Newport News & Miss. Valley R.R., 34 W. Va. 538, 12 S.E. 532 (1890).

Thus, railroad is not liable if contributory negligence is proximate cause.—Where one is injured by carelessly driving on a railroad crossing in front of a moving engine or train, the proximate cause of his injury must be regarded as his contributory negligence, and not the negligence of the railroad company in failing to ring the bell or blow the whistle. Cline v. McAdoo, 85 W. Va. 524, 102 S.E. 218 (1920).

Where the only evidence was that the warning signals required by this section were not given, and that the failure to do so constituted negligence on the part of defendant, it was held that notwithstanding defendant's negligence, if deceased's contributory negligence is established as a matter of law, plaintiff can have no recovery. Arrowood v. Norfolk & W. Ry., 127 W. Va. 310, 32 S.E.2d 634 (1944).

And signal requirement does not relieve traveler of exercising ordinary care. — Failure to ring bell or blow a whistle [illegible] a railroad track from the exercise of such reasonable care and caution as the law requires, to ascertain whether a train is approaching the crossing. Beyel v. Newport News & Miss. Valley R.R., 34 W. Va. 538, 12 S.E. 532 (1890); Hassford v. Pittsburg, Cincinnati, Chicago & St. Louis Ry., 70 W. Va. 280, 73 S.E. 926 (1912); Cline v. McAdoo, 85 W. Va. 524, 102 S.E. 218 (1920); Robinson v. Chesapeake & O. Ry., 90 W. Va. 411, 110 S.E. 870, 22 A.L.R. 892 (1922); Cavendish v. Chesapeake & O. Ry., 95 W. Va. 490, 121 S.E. 498 (1924); Gray v. Norfolk & W. Ry., 99 W. Va. 575, 130 S.E. 139 (1925); Berkeley v. Chesapeake & O. Ry., 43 W. Va. 11, 26 S.E. 349 (1896).

Though a traveler has the right to assume that warning signals required by this section will be given, failure to give them will not excuse him from exercising ordinary care, and taking the necessary precautions for his safety. Arrowood v. Norfolk & W. Ry., 127 W. Va. 310, 32 S.E.2d 634 (1944).

III. EVIDENCE.

The burden of proving that signals were not given rests upon the plaintiff. Parsons v. New York Cent. R.R., 127 W. Va. 619, 34 S.E.2d 334 (1945).

No conflict in evidence where some witnesses heard signals and some did not.—The fact that witnesses have heard signals given by a locomotive approaching a crossing warning travelers of danger, is not necessarily in conflict with the evidence of other witnesses who did not hear them; for the observation of the fact by those who heard is consistent with the failure of the others to hear them. Cavendish v. Chesapeake & O. Ry., 95 W. Va. 490, 121 S.E. 498 (1924).

Unless witnesses not hearing had equal opportunity to do so. — Testimony with reference to the statutory warning signals which only goes so far as to establish that the witnesses did not hear the bell rung and the whistle sounded is not in conflict with the testimony of other witnesses who testified that in fact the whistle was blown and the bell rang. An exception to the foregoing rule arises where there was equal opportunity of a witness to hear the [illegible] & Smith, [illegible] W. Va. [illegible], 74 S.E.2d 767 (1953).

Witnesses in position to observe but not hearing signals are entitled to peculiar weight.—Where the witnesses were in a position to observe with unusual care the circumstances surrounding the accident, their testimony as to the neglect to sound the customary warnings by bell or whistle, or both, within a reasonable distance from the crossing, a duty dictated by reason and required by this section, is entitled to peculiar weight. C[illegible]dorph v. Hines, 89 W. Va. 148, 109 S.E. 771 (1921), citing Carnefix v. Kanawha & Mich. R.R., 73 W. Va. 534, 82 S.E. [illegible] (1914); Southern Ry. v. Bryant, 95 Va. 213, 28 S.E. 183 (1897).

Thus, denial that signals were given may produce jury question.—The testimony of one witness, who denies that a railroad whistle was sounded on a given occasion, is as positive evidence as the testimony of another who affirms the fact, where each has equal opportunity of hearing and the attention of the former because of special circumstances is equally drawn with that of the latter to the sounding of the whistle. The denial by the one and the affirmance by the other produces a conflict of evidence, which it is the province of the jury to determine. Tawney v. Kirkhart, 130 W. Va. 550, 44 S.E.2d 634 (1947).

Whether a conflict arises between positive and negative evidence of this character depends upon the facts and circumstances of each case, from which it may be determined whether such negative evidence has any probative value. Cavendish v. Chesapeake & O. Ry., 95 W. Va. 490, 121 S.E. 498 (1924); Tawney v. Kirkhart, 130 W. Va. 550, 44 S.E. 631 (1947).

Since, if evidence conflicts, question is for jury.—Where the evidence as to blowing the whistle and ringing the bell is in conflict, the question of fact is one to be determined by the jury. Kelley v. Kanawha & Mich. Ry., 99 W. Va. 5[illegible], [illegible] S.E. 677 (1925); Tawney v. Kirkhart, [illegible] W. Va. 550, 44 S.E.2d 634 (1947).

Where the evidence conflicts and [illegible] credible, the question is one for the jury. Parsons v. New York Cent. R.R., 127 W. Va. 619, 34 S.E.2d 334 (1945).

Where the evidence conflicts [illegible] v. Norfolk & W. Ry., [illegible] S.E. 563 (1926).

Question of traveler's contributory negligence held for jury.—See [illegible] v. Norfolk & W. Ry., 127 W. Va. 310, 2 S.E.2d 631 (1944).

Evidence held insufficient to submit railroad's negligence to jury. — In action for injuries sustained in crossing collision evidence was insufficient to justify submission to jury of question of railroad's negligence in failure to comply with this section. Baltimore & O.R.R. v. Deneen, 161 F.2d 674 (4th Cir. 1947).

Evidence held sufficient to sustain verdict for either party. — Conflicting evidence on question of whether railroad gave statutory warning signals required by this section was sufficient on both sides to have sustained a verdict in favor of either party. Tawney v. Kirkhart, 130 W. Va. 550, 44 S.E.2d 634 (1947).

Evidence held to favor railroad's compliance with section.—In Krodel v. Baltimore & O.R.R., 99 W. Va. 374, 128 S.E. 824 (1925), there was some conflict of testimony as to sounding the whistle and ringing the bell at a railroad crossing, but it was held that the weight was in favor that the defendant complied with the statute.

ENCLOSURE C

MULTIDISCIPLINARY ACCIDENT INVESTIGATION

Case No. UC852D

(Abridged)

Prepared by

University of California
Los Angeles, California

The contents of this report reflect the views of the performing organization which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification or regulation.

UCLA COLLISION INVESTIGATION PROGRAM

VEHICLE COLLISION REPORT

Prepared for the U.S. Department of Transportation
National Highway Safety Bureau,
Under Contract FH-11-6690

Certain information contained in this report is obtained from indirect sources.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily of the National Highway Safety Bureau.

U. C. 852D

1. STANDARD CASE SUMMARY

1.1 SUMMARY TEXT

IDENTIFICATION: This train versus automobile collision occurred on a Thursday at 10:51 a.m. at a combination intersection/railroad crossing in California. Maximum occupant injury severity: critical (06) Collision causation: driver inattention.

AMBIENCE: Day; weather clear and dry; roadway dry.

ROADWAY: A straight, asphalt, undivided roadway, 75 ft. wide with curbs, in a suburban area with speed limit of 35 mph. The collision site is at a railroad crossing, 25 feet before a T-intersection. The road has a negligible crown, and is upgrade at the site. The roadway has three intersections within one-quarter mile of this intersection.

TRAFFIC CONTROLS: The lanes are separated by broken white lines with opposing lanes divided by double-double yellow lines. There is a railroad automatic signal and a traffic signal at the railroad crossing. There were no crossing gates at the time of the collision. Four auto/train collisions at this site in past 3 yrs.

VEHICLES: Vehicle #1: Freight train weighing approximately 400 tons. Vehicle #2: 1967 Cadillac Coupe de Ville two-door hardtop with power windows and seat. No apparent defects. Collision damage to right door causing intrusion of 12". Occupant contact with intruding door and train. Deformation Index: 03RPMW2.

OCCUPANTS: Vehicle #2: Driver: 59-year-old female, height, 64", weight, 160 lbs. Lap belt in use. No HBD or drugs. Injuries: fractured rib, lumbar back strain, abrasions, and contusion.

Right Front: 63-year-old female. No restraint in use. No HBD or drugs. Injuries: compound, depressed skull fracture with cerebral contusion, abrasions and contusions over body.

DESCRIPTION:

Pre-collision: Vehicle #2, the Cadillac, approaching the T-intersection, failed to stop at the railroad crossing in spite of the warning lights and bell. Slowing for the red light at the intersection, the Cadillac entered the tracks, into the path of the train. The train was eastbound at approximately 15 mph, approaching the crossing. The train engineer was sounding the whistle and applied his brakes when he saw the Cadillac in crossing.

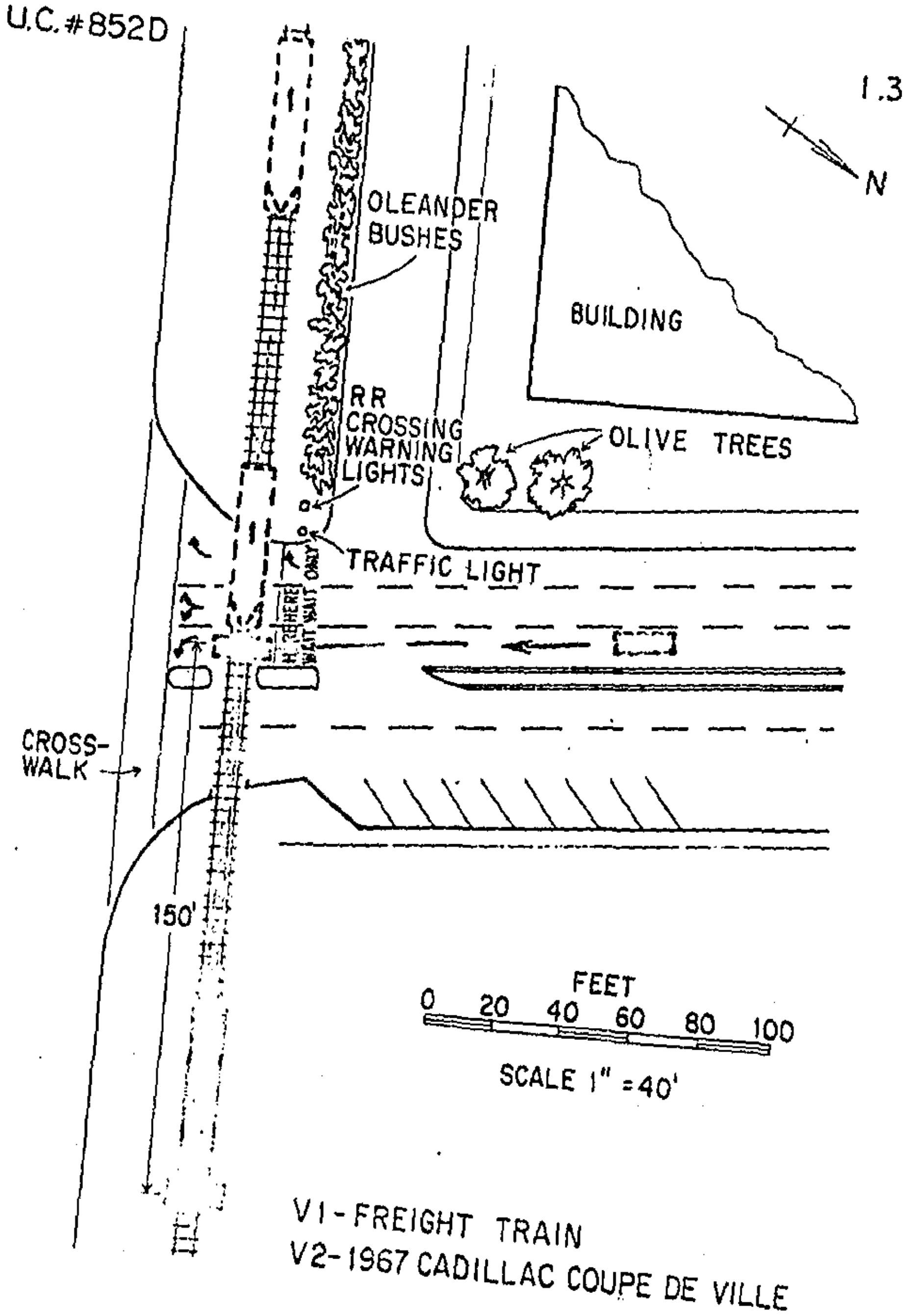
U. C. 852D

Collision: The train struck the Cadillac in the right side, pushing it 150 ft. along the railroad tracks. The Cadillac remained in a position at a right angle to the railroad tracks. Occupants of the Cadillac moved to the right, and the right front occupant was struck by the intruding train.

Post-collision: Occupants were hospitalized. Railroad crossing gates were later installed at the crossing.

1.2 CAUSAL FACTORS, CONCLUSIONS, RECOMMENDATIONS:

Matrix cell (*indicates positive factor)	Explanation
1	Driver inattention and/or distraction appear to be the chief cause of this collision.
4	Air conditioning on, with windows rolled up, makes it difficult to hear train or warning bells.
5	Right door penetration of 12" due to side impact. Door metal torn in area of hinges.
5	It is recommended that integrated side structures be employed, combining strength of frame, door sill, body pillars and roof.
5*	Right door latch and hinges did not fail.
7	Driver's view of oncoming train partially blocked by shrubbery along tracks.
7	Vehicles were allowed to stop on railroad tracks while waiting to turn at intersection.
7	It is recommended that visibility of oncoming trains be maximized by removing obstructions. Vehicles should not be allowed to wait on railroad tracks.
8*	Railroad crossing gate was installed and light locations were altered after the collision.


U.C. #852D
1.3
N
OLEANDER BUSHES
BUILDING
RR CROSSING WARNING LIGHTS
OLIVE TREES
TRAFFIC LIGHT
CROSS-WALK
150'
FEET
0 20 40 60 80 100
SCALE 1" =40'
V1-FREIGHT TRAIN
V2-1967 CADILLAC COUPE DE VILLE

ENCLOSURE D

SOUTHWEST RESEARCH INSTITUTE

CASE SUMMARY
(MV-TRAIN–INTERSECTION COLLISION)
Case No. 7173

(Abridged)

IDENTIFICATION

This accident occurred at the MKT railroad grade crossing on Eisenhauer Rd. at IH35 in San Antonio, Bexar County, Texas, on Thursday, September 30, 1971 at 1335 hours, involving the collision of a diesel freight engine and a 1970 four-door station wagon with a lone driver. The westbound automobile was struck on its left side by the northbound locomotive. The area is residential. The accident was injury-producing; AIS Severity Code No. 3.

AMBIENCE

It was daytime with partly cloudy skies, 85°F dry bulb, 57 percent relative humidity, 10-mph breeze blowing from the southeast; the road surfaces were dry and clear of debris and loose gravel.

HIGHWAY

Eisenhauer Rd. is a major access artery between the interstate loop expressway system and the residential areas of northeast San Antonio. It is a 41-ft-wide, four-lane, two-way roadway with an asphalt surface of the intermediate type in good condition. The road is divided at this immediate area of the IH35 access road–Eisenhauer Rd. intersection by 6-in.-high concrete channelizing islands. The traffic lanes are 10 ft wide. Eisenhauer Rd. runs east-west and is bounded on both sides by a 6-in. curb. The road is straight and level. It is not crowned. The coefficient of friction on the dry surface was 0.61. A southbound, one-way, two-lane 24-ft-wide frontage road runs 60 ft east and parallel to a mainline, single track railroad right-of-way, both intersecting Eisenhauer Rd. at this point. An exit ramp from IH35 is immediately north of this intersection and an entrance ramp is immediately south. These ramps connect IH35 to the frontage road.

TRAFFIC CONTROLS

The posted speed limit on Eisenhauer Rd. is 30 mph. The speed limit is 40 mph on the frontage road. A railroad company-imposed speed limit of 25 mph is assigned for 0.5 mile each side of the crossing. Traffic control devices consist of pavement markings, 6-in.-high channelizing islands, regulatory, warning, and guide signs. There are two flashing amber lights, 36-in.-diameter yellow railroad advance warning signs, and black-on-white railroad crossbucks. There are neither traffic control signal(s) in the area nor a flashing red light or bell warning signals, gates, or guards to provide immediate warning of an approaching train.

VEHICLES

No. 1. 1968 GP40 Electromotive diesel freight engine. The 3-yr-old engine is considered to be in good operating condition with no indicated defects. Minor secondary damage includes bent brakeman's steps, bent coupling actuator lever, and airhose torn loose, secondary vehicle deformation index 12FDLW1. The retail repair cost was nil.

No. 2. 1970 Oldsmobile Vista Cruiser, four-door, three-seat, yellow station wagon; odometer reading 22,224 miles; valid Texas Motor Vehicle Inspection sticker with a damaged illegible date; equipped with a standard 350-cu in. eight-cylinder gasoline engine; automatic transmission, power steering, and power front disc-type brakes; radio, heater, air conditioner, and tape deck; padded armrests, sunvisor, seat back tops, interior rearview mirror, windshield interbeam, and instrument panel. Three seatbelts and two shoulder straps for front bench-type seat and three seatbelts for the second bench-type seat. The shoulder straps were in the stored position. No defects were apparent or indicated. The last vehicle maintenance w performed at 13,663 miles on January 21, 1971 and included lubrication and oil and filter change. Prima contact damage was 16-in. sheet metal and frame deformation to the left side, primary vehicle deformati index 09LPAWS. Secondary damage was to the tires, rear bumper, and roof. The retail replacement val was $3075 (total less $200 salvage value).

OCCUPANTS

Vehicle No. 1. Engineer: 46-yr-old white male, 71 in., 155 lb (estimated). An interview was no obtained. He was familiar with the vehicle and the route traveled.

Injury: None.

Vehicle No. 2. Occupant No. 02. Driver: 42-yr-old white female of Latin-American extraction, 62 in., 132 lb. She has been driving 20 yr and currently drives approximately 9000 miles/yr. She was en route from her husband's office to home, a distance of 10 miles. The accident occurred 1 mile from her destination. She had no definite ETA. She was familiar with the vehicle and with the route traveled. She has had no formal driver's education. Her physical condition was excellent. Her precrash state was rested with no stress; she was inattentive to her driving task. Lap and shoulder restraints were available, but not in use.

Injury: Severe (not life-threatening). AIS Severity Code No. 3.

STANDARDS

The following Highway Safety Program Standards (HSPS) and/or Motor Vehicle Program Standards (MVPS) were relevant to this case:

HSPS No. 4–*Driver Education Use of Occupant Restraints, Radio, and Failure to Look for Train*
HSPS No. 9–*Identification and Surveillance of Accident Locations*
HSPS No. 13–*Traffic Control Devices*
MVPS No. 201–*Occupant Protection in Interior Impact*
MVPS No. 214–*Side Door Strength.*

DESCRIPTION

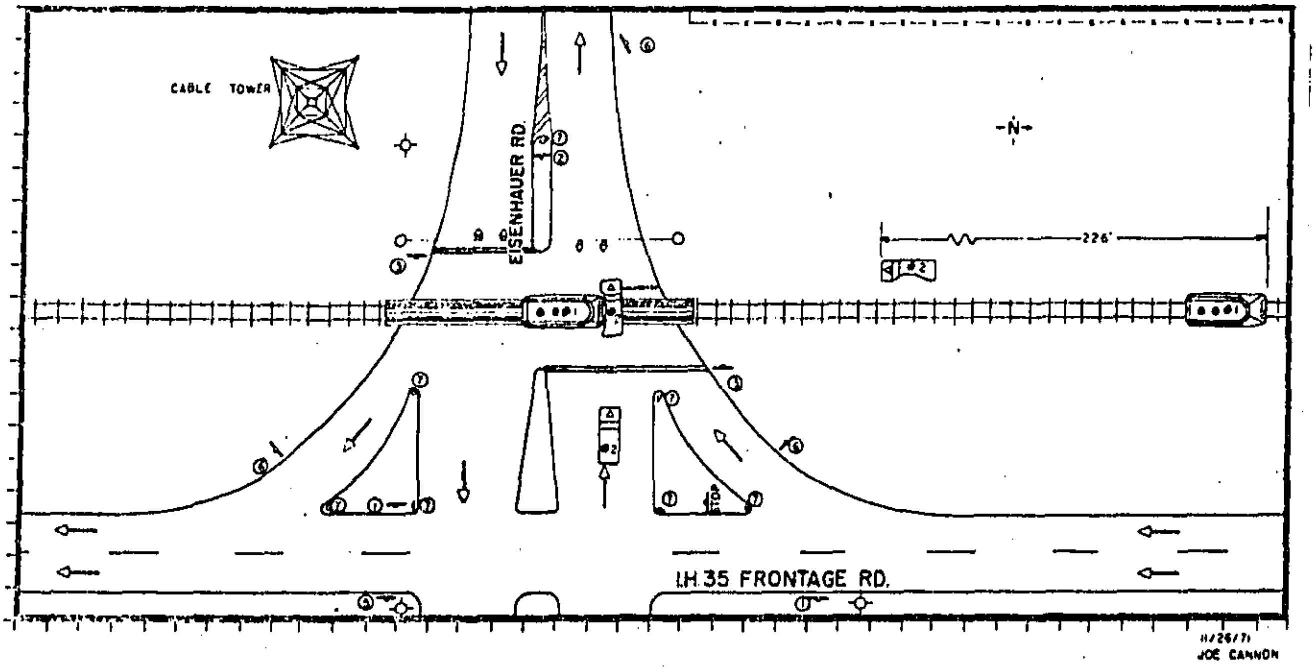
Precrash: The driver of vehicle No. 2 (passenger car) was traveling to her home from her husband's office. She had left northbound IH35 and turned west onto Eisenhauer Rd., passing under the IH35 overpass. She crossed the southbound frontage road at a relatively low speed (estimated not more than 25 mph) and drove in front of vehicle No. 1 (diesel freight engine), which was moving north at about 25 mph with its horn blowing for the crossing. There were no skidmarks from vehicle No. 2 prior to impact. The car radio was in operation.

Crash: Impact occurred on the left side of vehicle No. 2, centered approximately at the "A" pillar line, as it crossed the railroad track in front of vehicle No. 1. The coupler of the freight engine forced in the forward portion of the door structure, firewall, cowl, and instrument panel structure. Other portions of the front structure of the engine - brakeman's steps and brackets–forced in the doors, floor, and frame left siderail to a depth of 16 inches. The passenger vehicle was pushed northward on the railroad right of way. It then yawed left and came to rest 88 ft from the impact point, parallel to and 7 ft west of the tracks facing the crossing. The unrestrained driver was first thrown left against the incaving side structure of the car. Then she was thrown to the right. Vehicle No. 1 stopped 314 ft from the point of impact.

Postcrash: The driver of vehicle No. 2 was not ejected from the vehicle. She was removed from vehicle No. 2 through the right front door without complications. She was taken to the hospital by ambulance approximately 20 min after the crash. Because the automobile came to rest a considerable distance from the roadway, there was no appreciable interference with traffic. A wrecker had no complications in picking up the vehicle and towing it away. Since the locomotive was not significantly damaged, it was able to proceed. Traffic on Eisenhauer Rd. was estimated at 15 vehicles/min; on the frontage road, traffic was estimated at 5 vehicles/min.

CAUSAL FACTORS, CONCLUSIONS, AND RECOMMENDATIONS

Matrix Cell (* Indicates Positive Factors)	Explanation
1	Driver No. 02 was inattentive and did not observe normal precautions when approaching the railroad track.
1	Driver No. 02 had her radio on and windows up, which may have prevented or seriously interfered with her ability to hear the train's signal horn.
1	The engineer may have been speeding, with respect to the company-imposed limit of 25 mph, 40 to 50 mph. This is the situation if the train brakes were adequate and if the engineer maintained a locked brake mode throughout the stopping sequence.
2	Driver No. 02 was not wearing the available seatbelt or shoulder strap.
3	Driving in a veil of interior noise (radio, air conditioner, etc.) with the windows closed should be discouraged in driver education programs.
4	The train should have been capable of stopping within 104 ft from 25 mph. The 314-ft stopping distance, from the point of impact, suggests that either the driver did not fully apply the brakes at some point during the collision sequence or that the brakes were not performing adequately.
*5	Occupant injuries from impact against interior surfaces and protuberances were mitigated as a result of adequate padding and interior design.
7	This site has an extremely high accident rate; however, more adequate traffic control by a train-approach signal system has not yet been authorized.



LEGEND

1. ONEWAY
2. KEEP RIGHT
3. RAILROAD CROSSBUCK
4. NO PARKING ANYTIME
5. I.H. 35 SOUTHBOUND
6. YIELD
7. REFLECTOR

COLLISION SCENE SCHEMATIC

ENCLOSURE E

Maryland Medical-Legal Foundation

Office of the Chief Medical Examiner

State of Maryland

Truck/Train Impact

Case # MMF 72-24

(Abridged)

MULTIDISCIPLINARY ACCIDENT INVESTIGATION SUMMARY

IDENTIFICATION OF COLLISION

The highway is a state road traversing north and south in the southeast portion of an industrial section of Baltimore County. The accident occurred in September of 1972 at 0400 hours on a Friday involving a tractor trailer and a freight train at a front to side impact. The accident caused fatal injuries to the driver of the tractor trailer.

INJURY SEVERITY SCALE: Driver of Vehicle #1 FATAL-AIS-8

AMBIENCE

Night; no illumination; misty; 58 degrees F.; 60% relative humidity; wind 10 m.p.h. from the northwest; visibility of 500 feet; road surface was wet; coefficient of friction .55 dry (measured) and .45 wet (estimated).

HIGHWAY

The highway on which the accident occurred is a major arterial state road with a total width of 106 feet consisting of two 12 foot lanes going north and two 12 foot lanes going south divided by a 48 foot grass median. The roadway is of black top macadam with an 8 foot shoulder on the east side and a 2 foot shoulder on the west side. The roadway is straight and level. There is no artificial lighting and within ½ mile there are two intersections; one being 800 feet south of the railroad crossing and the other being 600 feet north. There are 9 telephone and transit poles within ½ mile. The accident history at this point within a year previous is 6 property damage and 3 personal injury accidents with an average daily traffic of 22,500 vehicles.

TRAFFIC CONTROLS

The speed limit is posted at 55 m.p.h. and there are intermittent lane lines with solid edge lines painted in the roadway. There are standard railroad crossing signs and lights at the right side of the road with overhead signals actuated by the train.

VEHICLES INVOLVED

Vehicle #1 was a 1969 G.M.C. Tractor, two-door, red in color with an odometer reading of 49,760 miles. There is no inspection data but the vehicle was well maintained by the company garage. The vehicle was equipped with manual steering, manual transmission, air brakes (drum type), seat belts (being used by the driver when the accident occurred). There was no previous damage noted. Damage to Vehicle #1 on impacting the train at an eleven o'clock principal impact force was to the left front causing a sheet metal crush of 38 inches. The bumper, grille, fender and hood deformed rearward into the engine compartment whereby the engine separated from mounts. The left front wheel and assembly moved rearward. The seats moved forward and the driver impacted the steering wheel and column with his chest and his head impacted the left A-Pillar as it was deformed inward and rearward. After the initial impact a second impact of 06 hours principal force occurred as the trailer sheared from the fifth wheel and impacted the rear of the cab with a sheet metal crush of 18 inches compressing the cab interior by 50% pinning the operator in.

VEHICLE DEFORMATION INDEX: Principal Impact - 11 FLAW-4
Secondary Impact - 06 BDHW-4

Vehicle #2 was a General Motors E.M.D. type locomotive pulling 47 box cars and it sustained minor damage to the right front side.

VEHICLE DEFORMATION INDEX: 02 RFMW-1

OCCUPANT DATA

The driver of Vehicle #1 was a 46 year old white male, 68 inches tall, weighing 115 pounds having 30 years driving experience at approximately 15,000 miles per year. At the time of accident he was enroute from his place of employment with a delivery for a distant city expected to arrive 5 hours after the accident occurred. The accident occurred within 5 miles from the origin. He was familiar with the vehicle and the area having used both daily for the past several years. His physical condition was normal as was his mental condition. There was no alcohol or drug involvement and seat belts were available and in use by the operator. During the accident the driver sustained the following injuries: fractures of skull, ribs, pelvis and extremities, contusions of lungs with hemothorax, laceration of heart, laceration of liver and spleen with hemoperitoneum, rupture of bladder; and contusions of hippocampi and temporal lobe of brain. (AIS-8)

The driver of Vehicle #2 (train) was a 57 year old white male, weight and height unknown having 40 years driving experience with 15 years as a railroad engineer. His driving record is good with 10,000 miles per year plus rail usage undetermined. He is familiar with the engine using same three to four times weekly. At the time he was shifting cars along the railroad from yard to yard. His engineering ability was taught to him by the railroad company. There were no drugs or alcohol involved. There were no restraints available and no injuries. There were three passengers on the train and they were not injured or restrained. Passenger #1 was a white male, 56 years of age and he was seated in the front center. Passenger #2 was a white male, 36 years of age and he was seated in the front right. Passenger #3 was a white male, 54 years of age and he was seated in the rear left.

STANDARDS

1. FHSPS #9 - Identification and Surveilance of Accident Locations. The railroad crossing is well protected with traffic signals actuated by the train, but it is so little used that drivers attempt to beat the train. It is recommended that gates be installed at the railroad crossing..

COLLISION DESCRIPTION

Pre-Crash

The driver of Vehicle #1 reported to work at the usual time, 0130 hours, and had proceeded from the terminal to deliver a load of hardware to a distant city. He was operating the vehicle northbound on a state road at an estimated speed of 45 to 50 m.p.h. and when he approached the east/west railroad crossing he failed to stop for the signals and collided with the right front side of a slow moving freight train. The freight train was proceeding eastbound at an approximated speed of 8 to 10 m.p.h. There is no evidence to show that the driver of Vehicle #1 tried to take any evasive action, however, the operator of the train did apply his air brakes for an emergency stop.

Crash

Vehicle #1 impacted the right front side of the train with its left front at an eleven o'clock principal force impact with a secondary impact force of 06 o'clock when the trailer sheared off the fifth wheel and impacted the rear of the truck cab. As the vehicle rotated 25° clockwise, and coming to rest 42 feet east of the impact, the driver, who was restrained, moved forward and to the left impacting the steering wheel and the left A-Pillar and was impacted from the rear by the cab body and seat.

Vehicle #2 was impacted at the right side at front initial impact force at 02 o'clock deforming the entrance steps and the hand rail. The unrestrained occupants were well to the rear of the impact point and suffered no effects of the accident. The driver of the train applied his air brakes for an emergency stop and the train remained on the rails coming to a stop 168 feet east of the impact.

Post-Crash

Vehicle #1 came to rest 42 feet east of the impact facing east off the roadway and Vehicle #2 came to rest 168 feet east of the impact, on rails. The operator and passengers of Vehicle #2 were unhurt. The operator of Vehicle #1, due to the compression of the truck cab from the front and rear impacts, was pinned in the cab. Emergency rescue equipment of the Police and Fire Departments were called, responding within 10 minutes and proceeded to cut the metal attempting to free the driver. Due to severe deformation, extrication was difficult and took two hours to free the driver. He was pronounced dead at the scene and was taken to the Office of the Chief Medical Examiner. During the rescue operation, traffic was tied up in both directions and suitable detours were maintained by the police. A two company was contacted to clear the scene of the truck and debris. The truck was towed to the terminal and the train was moved under its own power. The scene was cleared and open for traffic within four hours.

CAUSAL FACTORS, CONCLUSIONS AND RECOMMENDATIONS

ACCIDENT CAUSATION

Matrix Cell	Explanation
	Primary Cause
1	Driver of Vehicle #1 failed to perceive the approaching train and danger of going through signals. (Definite)
	Severity Increasing
1	Driver of Vehicle #1 made no attempt at evasive action. (Definite)
	Relevant Conditions
1	Driver of Vehicle #1 was apparently preoccupied with thoughts of his trip. (Probable)
7	The crossing was well protected with actuated signals (at side and overhead) but it allows room for passage. (Probable)

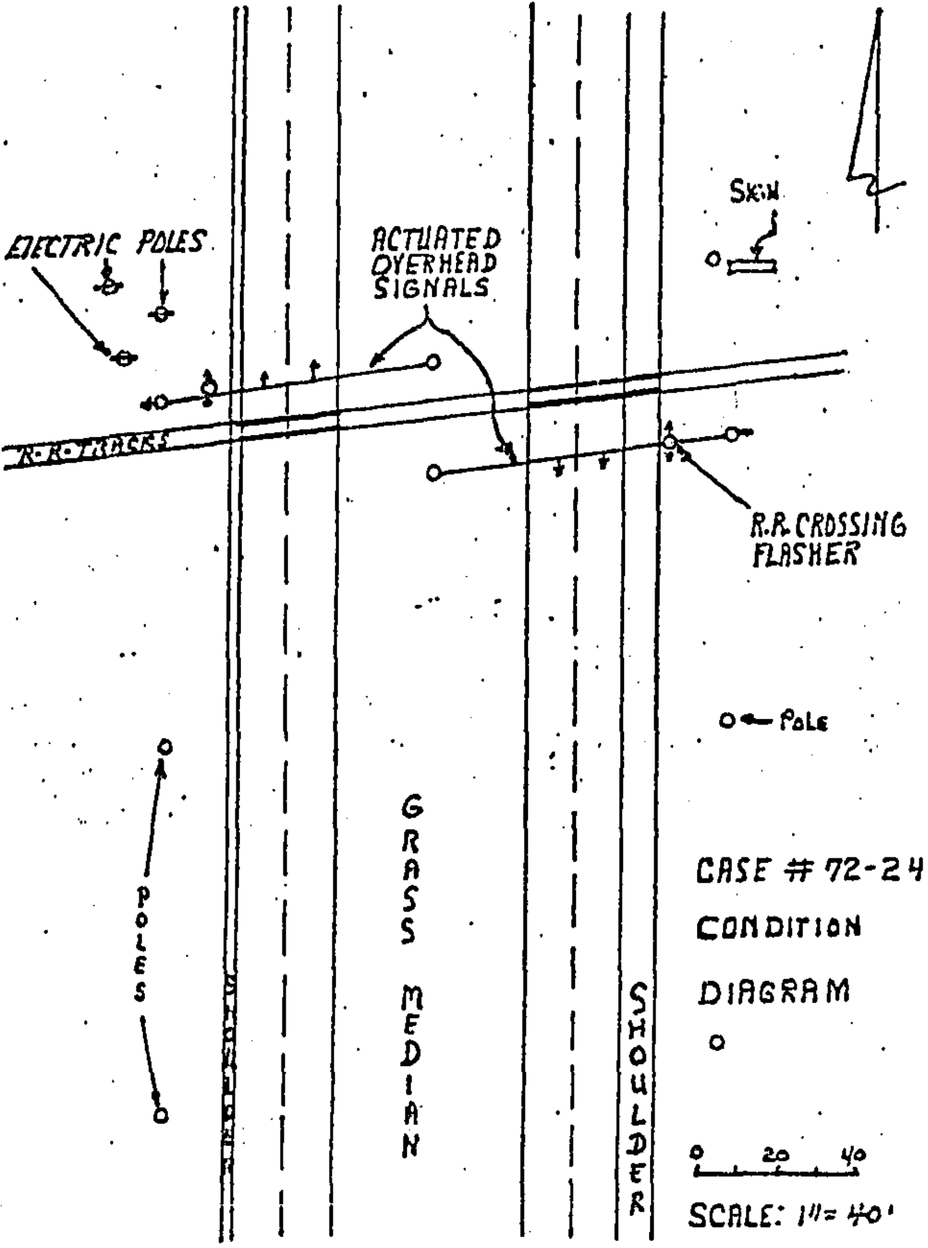
INJURY CAUSATION

Matrix Cell	Explanation
2	Driver of Vehicle #1 was wearing available restraints but they were of no use in this case. (Probable)
5	The collapse of Vehicle #1 from front and rear impacts added to severe injury. (Definite)

POST-CRASH FACTORS

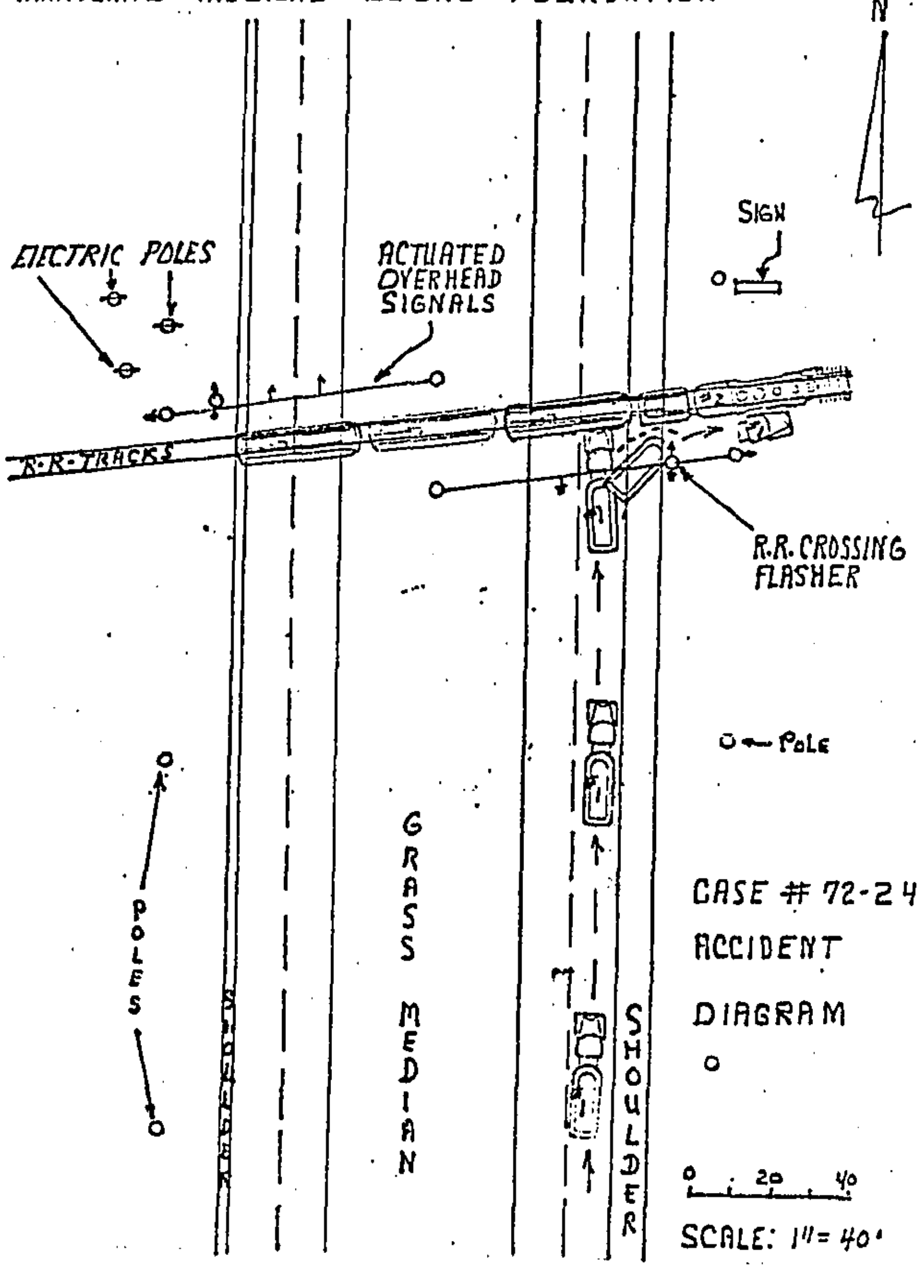
Matrix Cell	Explanation
3	Ambulance and rescue arrival within 10 minutes, but extrication was difficult taking two hours with metal saws. (Definite)
6	The load of Vehicle #1 shifted after the initial impact. (Definite)
9	There were no fires or explosions, detours were set and maintained adequately, and the clean-up operation took four hours. (Definite)

MARYLAND MEDICAL-LEGAL FOUNDATION



CASE # 72-24
CONDITION
DIAGRAM

MARYLAND MEDICAL-LEGAL FOUNDATION



CASE # 72-24
ACCIDENT
DIAGRAM

SCALE: 1" = 40'

ENCLOSURE F

Durham City Code
Durham, N.C.

Ch. 18 § 9 Locomotive Whistle.

It shall be unlawful for any person to blow or allow to be blown any locomotive whistle under his control within the city limits. (Code 1940, C. 28, § 8.)

Knoxville City Code
Knoxville, Tenn.

Ch. 33 § 8 Blowing Whistles.

It shall be unlawful for any person operating or in charge of a locomotive engine within the corporate limits of the city to blow the whistle on the same except as may be absolutely necessary in the use of the signals as laid down by the rules and regulations of railway companies, or as required by the laws of the state. (10-21-04.)

Houston City Code
Houston, Texas

Sec. 1843 Blowing Whistles; Blowing out Boiler

All persons are prohibited from blowing any whistles on any locomotive, or single blasts therefrom, within the limits of the city, for a longer period of time than five seconds, except when there is imminent danger of an accident. All persons are prohibited from blowing off or blowing out a boiler when crossing any public street or other thoroughfare within the limits of the city. Each and every person violating any provision of this section shall be fined in any sum, upon conviction, not less than five dollars and not exceeding fifty dollars.

Mason City, Iowa

26-29 Sounding of Locomotive Whistles

It shall be unlawful for any person to cause or permit any locomotive whistle to be sounded within the limits of the City except for the purpose of making necessary signals required by law or required for the safe operation of the railway, and where requisite signals cannot be made by other means. (R '16, Sec. 545.)

Chicago, Illinois

188-44. No person owning or operating a railroad shall cause or allow the whistle of any locomotive engine to be sounded within the city, except necessary brake signals and such as may be absolutely necessary to prevent injury to life and property.

Each locomotive engine shall be equipped with a bell-ringing device which shall at all times be maintained in repair and which shall cause the bell of the engine to be rung automatically. The bell of each locomotive engine shall be rung continuously while such locomotive is running within the city, excepting bells on locomotives running upon those railroad tracks enclosed by walls or fences, or enclosed by a wall on one side and public waters on the other side, and excepting bells on locomotives running upon those portions of the railroad track which have been elevated. In the case of these exceptions, no bell shall be rung or whistle blown except as signals of danger.

Buffalo, New York

Chapter V. RAILROADS

#4. It shall not be lawful for any person in the employ of any railroad company operating within the limits of the city to permit the whistle of the locomotive under his control to be blown, except for necessary signal purposes. Any person violating the provisions of this section shall pay a penalty of $25.00 for such offense.

NOTE: This restriction is generally associated with a train speed restriction of 6 MPH and the use of flagmen.

Lynchburg, Virginia

CITY CODE SUPPLEMENT (Railroad)

Sec. 3809. Sounding whistles or horns.

The sounding or blowing of locomotive whistles or horns within the corporate limits of the city of Lynchburg is hereby prohibited, except as may be necessary for the transmission of signals or in emergency to prevent accidents.

The provisions of this section shall not apply to the two crossings of the tracks of the Chesapeake and Ohio Railway

Company at Reusens, in the vicinity of the E. J. Lavino Company, because of the lack of sight distance and warning devices at these crossings.

Any violation of this ordinance shall be punished by a fine of not less than five dollars nor more than ten dollars for each offense. (1931, §704; 6-8-42; 8=28-56; 10-9-56)

State of Illinois

Under authority delegated to it by the State Legislature (114-59), the Illinois Commerce Commission adopted General Order #176 on August 15, 1957, excusing the sounding of horns and whistles at crossings protected by flashing lights. This has now been incorporated in General Order No. 138, Revised, August 22, 1973, Rule 501.

State of Florida

§351.03 limits signals to bells only in incorporated areas, with an accompanying speed limit of 12 mph.

R006

ENCLOSURE G

COMMISSIONERS
VERNON L. STURGEON, PRESIDENT
WILLIAM SYMONS, JR.
J. P. VUKASIN, JR.
THOMAS MORAN
D. W. HOLMES

ADDRESS ALL COMMUNICATIONS
TO THE COMMISSION
CALIFORNIA STATE BUILDING
SAN FRANCISCO, CALIFORNIA 94102
TELEPHONE: (415) 557-1945

Public Utilities Commission
STATE OF CALIFORNIA

November 10, 1972

FILE NO. IC 79403

NOV 1

NOV 15 1972

Honorable Arlen Gregorio
The State Senate
12th District, San Mateo County
State Capitol
Sacramento, CA 95814

Dear Senator Gregorio:

Subsequent to receipt of your letter of October 4, 1972, our representative has discussed the use of train whistles approaching railroad grade crossings with Mr. John Gilroy and Ms. Charlotte Schultz of your staff.

As discussed with them, it may be necessary to sound the train whistle even at crossings equipped with automatic gates for the following reasons:

1. Possibility of a malfunction of the automatic grade crossing protection due to being struck by vehicles, vandalism or failure of track circuitry or signal apparatus.

2. Rail highway crossings are frequently traversed by bicyclists and pedestrians after the protective devices have been actuated by an approaching train.

3. Impatient motorists sometimes ignore crossing signals and have been known to drive around protective gate arms in an attempt to avoid being delayed by a train.

4. Liability on the part of the railroads for failure to use every means available to avoid an accident.

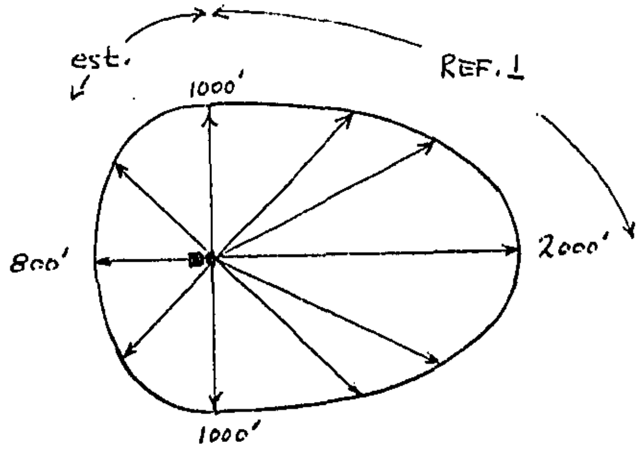
In view of the above, the staff feels that in the interest of safety, the railroads should not be prohibited from using the train whistles to warn persons that a train is approaching.

Yours very truly,

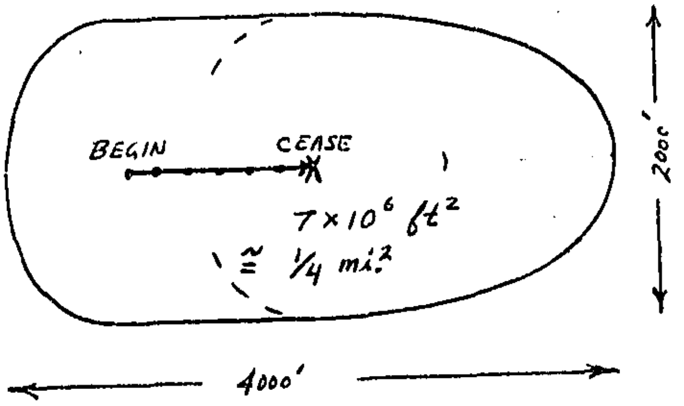
PUBLIC UTILITIES COMMISSION

By William R. Johnson
WILLIAM R. JOHNSON, Secretary

LOCOMOTIVE HORNS - AVERAGE NOISE PROPOGATION UNDER IDEAL CONDITIONS

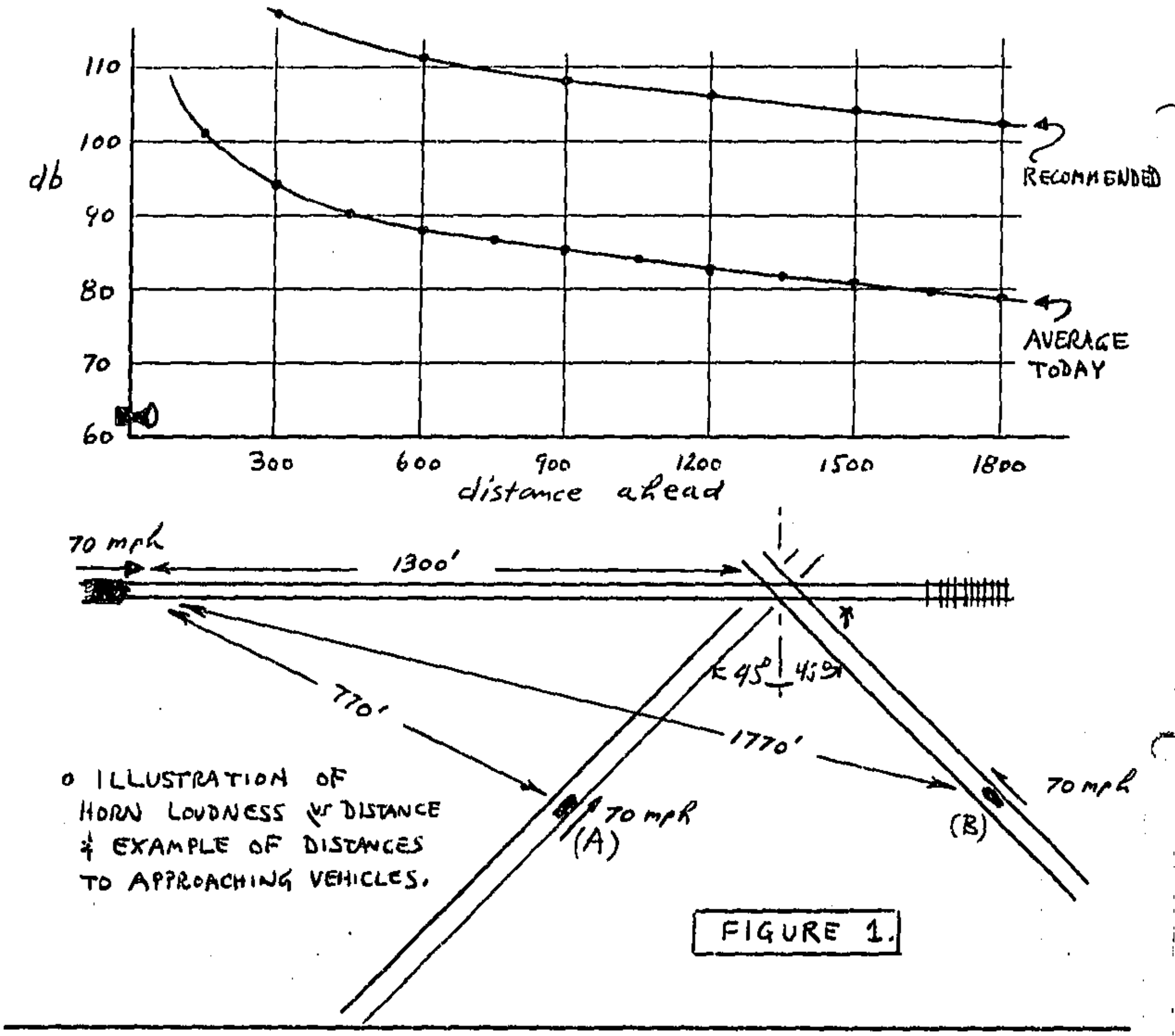


a) 77 db PROFILE



b) AREA SUBJECTED TO 77 db LEVEL OR MORE
Based upon extension of Profile along route.

FIGURE 2.



o ILLUSTRATION OF HORN LOUDNESS vs DISTANCE & EXAMPLE OF DISTANCES TO APPROACHING VEHICLES.

FIGURE 1.

TABLE 2.

VEHICLE SPEED	db Outside VEHICE for % of DRIVERS TO NOTICE	
	50 %	98 %
≤ 35 mph	83	101
36 – 50 mph	87	105
51 – 65 mph	91	109

Standard Deviation = 6 db

(Source: Ref 1)