LIA23651

LEAD INDUSTRIES ASSOCIATION, INC.

292 MADISON AVENUE

NEW YORK 17, N. Y.

March 27, 1963

SUBJECT: LEAD-ASBESTOS ANTI-VIBRATION PADS IN MONTREAL

To the Members of the Lead Industries Association, Inc.:

Attached is a reprint of an article which appeared in "The Engineering Journal" of the Engineering Institute of Canada in November, 1962, by a principal in the firm of consulting engineers for the Place Ville Marie Development in Montreal. It describes field tests of railroad vibration encountered in the area, tests on existing buildings nearby with lead-asbestos anti-vibration pads, and the methods used to isolate the new structures from this vibration, which includes lead-asbestos pads.

In the conclusion it is stated that "The studies outlined in this paper offer a sound approach to the resolution of a complex problem. The result indicated to the designers that a satisfactory solution was achieved within the scope of normal construction procedures. It is hoped that this paper may be of use to others in this field."

Because of the broad interest in the subject and the fact that this reprint contains about the only published engineering data on such vibration problems and their solution, we have had 15,000 copies printed and will distribute them to our mailing list of architects and structural engineers. Additional copies are available to members in quantities up to 25 free of charge and in larger quantities at our cost of $3.50 per hundred as long as our supply lasts.

Very truly yours,

Executive Vice President

RLZ:mk
Enc.

Look Ahead with Lead

1962 Annual General Meeting Paper No. 19

THE ISOLATION OF THE BUILDINGS IN THE PLACE VILLE MARIE DEVELOPMENT FROM RAILROAD-INDUCED VIBRATIONS

J. E. Brett, M.E.I.C.
Principal, Brett & Ouellette, Consulting Engineers, Montreal

Reprinted from THE ENGINEERING JOURNAL of the Engineering Institute of Canada, November 1962
Distributed by LEAD INDUSTRIES ASSOCIATION, INC., 292 Madison Ave., New York 17, N.Y.

LIA No. 39-D

The results of the noise and vibration survey given in this report have been taken largely from a report prepared for I. M. Pei and Associates by Bolt, Beranek and Newman, Inc.

THE ISOLATION OF THE BUILDINGS IN THE PLACE VILLE MARIE DEVELOPMENT FROM RAILROAD-INDUCED VIBRATIONS

J. E. Brett, M.E.I.C.
Principal, Brett & Ouellette, Consulting Engineers, Montreal

THE PLACE VILLE MARIE Development represents the culmination of four years of effort in the working drawing and construction stages. It can most easily be described in terms of the design and construction phasing of the project as follows.

Phase I. The 41-storey, cruciform-shaped Royal Bank Building, with its Plaza and lower levels covering a plan area of approximately 93,000 sq ft.

Phase II. The lower levels over the remainder of the site, covering an area of some 250,000 sq ft, together with the three-storey Cathcart Building and the projected 10-storey Mansfield Building.

The site of this project overlies a large portion of the Canadian National Railway Central Station railroad yard in downtown Montreal. The inter-relationship of the project phases and the principal adjacent structures is shown in Fig. 1. The prestige nature of the project made it imperative that further understanding of the cause and control of railroad-induced noise and vibration than was heretofore readily available be obtained. It is hoped that this work may be of use to others.

Noise and Vibration

The disturbance to the building occupants arising from the train movements may take the form of an unduly high vibration or noise, or both. The work "vibration" will indicate a structure-borne vibration, which, if sufficiently intense, may be "felt" by an occupant. The term "noise" will indicate a vibration "heard" rather than "felt". Since is it difficult (essentially impossible) to make complete data analyses during the short time of a train passage, magnetic tape recordings were made of all events and the records were analyzed later for noise and vibration intensity as a function of the frequency composition of the signal.

Railroad Practice

The use of built-up lead-asbestos isolator pads to minimize disturbances in terminal buildings has been standard practice with North American railroad companies for some time. The pad is made of two 1/8 in. thick layers of asbestos separated by a 1/16 in. sheet of galvanized steel and encased in a watertight envelope of 1/8 in. sheet lead. The asbestos component may vary from a soft fire-felt to a hard board depending upon the contemplated application. The pad is pre-compressed under a pressure of 200 p.s.i. and has a bearing capacity varying from 600 to 1000 p.s.i., depending on the form of the asbestos. Isolator pads of this type were installed in the foundations of the Queen Elizabeth Hotel, the asbestos being in the form of a cement-asbestos board. The data on the damping characteristics of the pads for design purposes was not found in the literature and was approximated from the measurement program outlined in the following section.

The Measurement Program

An extensive program was carried out at the site by the acoustical consultants on this project during February, 1959, to obtain data on the generation and transmission of railroad-induced noise and vibration into the contemplated structures. Tape recordings were made at various locations of the effects of more than 200 train movements in order to ensure statistical validity of the results with respect to the many variables in the problem. The records were later analyzed to determine the noise or vibration level in each of the frequency bands.

The generation of these disturbances was found to be affected by the following variables:

a) Train speed. Some train movements were at "platform-speed" and some at "yard-speed".

b) Equipment. Axle-loads of locomotives generated higher energy levels than those of the lighter cars.

c) Width of rail-joints. Noise arising from the presence of the main-rail-joints was found to be sufficiently high to warrant the taking of corrective measures.

d) Switches and frogs. Single-point frogs were found to be the most serious noise and vibration generators in this project.

e) Ballast. The solidly-frozen condition of the 2 ft. thickness of rock ballast overlying bed-rock undoubtedly had some effect on the measurements, although no quantitative studies were made to determine the influence of this factor.

The transmission of the disturbances was studied with respect to the horizontal and vertical distances from the tracks and the presence or absence of isolator pads in the adjacent structures.

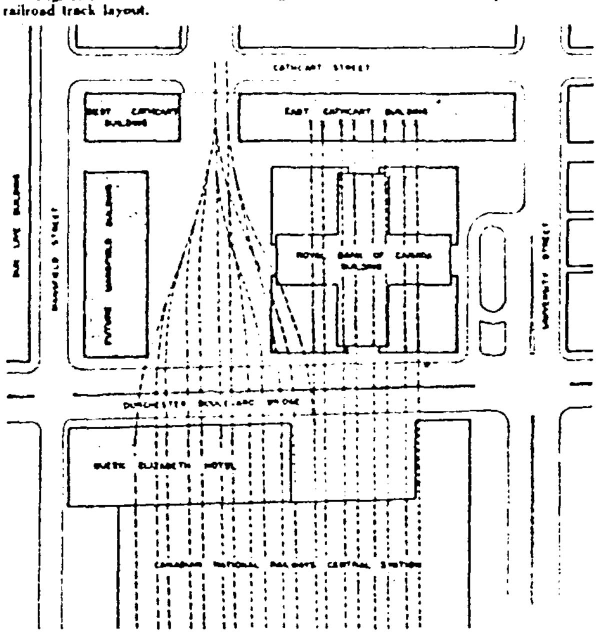
The program consisted of the measurement of the following effects:

a) Earth-borne railroad-induced vibration.

b) Structure-borne railroad-induced vibration in the isolated Queen Elizabeth Hotel and the unisolated Dorchester Street Bridge.

c) Radiated noise in the hotel and bridge structures.

Fig. 1. Plan view of site showing general arrangement of Development and the railroad track layout.



Three different arrangements of measuring equipment were used. In the first system used to record vibrations, the output of a Bruel and Kjaer accelerometer was connected through a bandpass filter to a vacuum-tube voltmeter to provide a direct-reading instrument in the sub-audio frequency bands of 2-4 cps, 4-8 cps, 8-16 cps, 16-32 cps and into the higher frequency audio bands. In the second type, comprising two complete systems, the output of each accelerometer was recorded on a magnetic tape and analyzed in the normal audio frequency bands of 20-75 cps, 75-150 cps, 150-300 cps and continuing up to 10,000 cps. The third system was used for radiated noise level measurements and comprised a microphone, sound level meter and octave band analyzer selected to cover the audio bands from 20 cps to 10 000 cps.

Consistent with the variety of conditions to be imposed by the Development, vibration measurements were made at 20 different locations ranging vertically from track level to elevations of 110 ft. above and horizontally over distances exceeding 200 ft. As a general rule, both the horizontal and vertical components of vibration were measured at all stations. Also, the two tape recorder systems were operated simultaneously so that the same event would be recorded on each system, the only differences being the intentional differences between the particular pick up points. In this way it was possible to accurately assess the vibration level differences that could be attributed to the measurement position differences. An important part of the program concerned the study of the effectiveness of the vibration isolator pads as used under the columns of the Queen Elizabeth Hotel. Many simultaneous recordings were made with one pick-up on an isolated Hotel column and one on an unisolated Bridge column.

Human Response to Noise and Vibration

It will be appropriate at this point to briefly discuss a few acoustical terms.

The noise in any environment is usually described by a graph of the sound pressure level as a function of the frequency distribution of the noise. The family of noise criterion, "NC", curves shown in Fig. 2 describe noise conditions judged to be acceptable by the average person for various situations. Human acceptance of these values is based on our acceptance of the balance of the sound pressure levels of the several frequency components of the noise. Noise becomes a disturbing element if such balances are not met, within reasonable limits, or if the absolute sound pressure levels are appreciably higher than the ambient noise levels in the space considered.

It has been found possible from acoustical studies to tolerate somewhat greater pressures of low frequency noise than indicated in the "NC" curves. The alternate noise criterion curves of Fig. 2 may then be used. The use of these alternate values may be considered in the design stages because of the preponderance of low frequency sounds in railroad-induced noise, the practical impossibility of their complete removal from the noise spectrum and last, but not least, their intermittency for the major portion of the normal office day.

The noise and vibration design criteria for the Royal Bank Building varied with the intended occupancy. The steady-state ambient noise levels in the executive offices and conference rooms were to be in the range of the NC-25 to NC-30 curves. The noise levels in private offices were to be in the NC-30 to NC-35 curves. The noise levels in the large, open office areas not involving business machines were to be in the NC-35 to NC-45 curves. For those areas involving business machines, the levels permitted corresponded to the NC-45 to NC-55 curves.

Fig. 3 summarizes the response of human beings to vibration. To verify the numerical values, train passages were found to be heard, but not felt in a fifth-floor hotel room. The measured vibration levels were in the range between −65 and −70 db re 1g in the 20 − 75 cps and 75-150 cps bands. The numerical values were thus found to be applicable.

Measurements

As previously indicated, extensive measurements were made to evaluate the contribution of each of the several factors to the noise and vibration environment to which the Development would be exposed. The vibration-isolated hotel, the unisolated bridge and the active railroad yard permitted the establishment of reference conditions and the measurement of data necessary to proceed from an existing structure to one in the design stages. Low levels of low frequency sound are more easily heard than the corresponding sound-producing vibrations are felt. For this reason, measurements were made of the noise levels rather than the vibration levels.

Effect of Height above Track Level

Radiated noise levels resulting from train movements at platform speeds on conventional track, without switches, were measured in hotel areas at different elevations, interest being taken in the frequencies between 20 and 600 cps. The areas were acoustically dissimilar and the measured noise levels were converted to equivalent levels in the reference room. Each equivalent noise level was then related to the highest NCA curve that had at least one point in common with it. The decrease of railroad noise levels with height for an isolated building was thus obtained and is shown for this project in Fig. 4.

Effect of Speed

It was found more difficult to isolate the effect of speed. Appreciable differences in the acceleration rates of the trains, different switch settings and differences in the rolling stock combined to mask this effect. It was noted that the vibration levels measured *near platforms increased* moderately with speed between the time the locomotive and the last car passed the measurement position. Trains travelling at yard speed were judged to be appreciably noisier than those travelling at platform speed and trains starting or stopping were judged to be somewhat less noisy than those at platform speed.

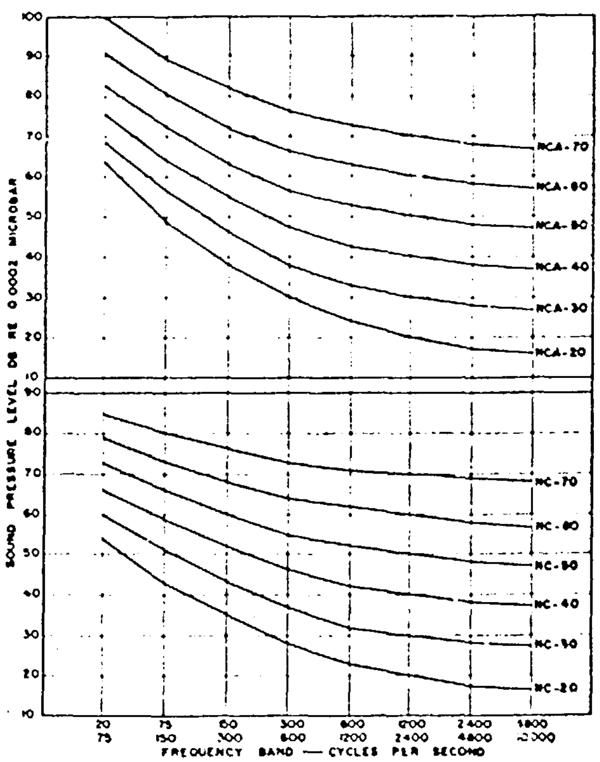


Fig. 2. "NC" and "NCA" noise criteria curves as per Bolt, Beranek & Newman Figures 1 and 2 of their final report.

Track Joints and Switches

The measurement of noise levels arising from track components gave interesting results. The passage of a wheel over a track joint appeared to be somewhat noisier than a wheel running on ordinary track. The welding of track then can be of importance.

Of greater importance was the fact that the passage of a wheel over the gap of a single-point frog appeared to be at least three times as noisy as that of a wheel over a track joint. It was estimated that the installation of a moving-point frog would offset the major portion of this increase.

Effect of Distance

The natural damping of vibration with distance was found to be of real significance with respect to this project. Also, during the working day, train movements tend to occur generally on widely-separated tracks, thus reducing the noise pressure at any one point in the building.

Isolator Pad Effectiveness

From the scientific point of view, the determination of the efficiency of the lead-asbestos isolator pads was of the greatest interest, since published data on their damping characteristics was not available. Three unisolated columns of the bridge structure and three adjacent isolated columns of the hotel structure provided a satisfactory setting for this investigation. These columns are situated in the vicinity of Track 7 near the western edge of the railroad yard. The measurements confirmed the usefulness of this type of pad in general, although some of the results were unexpected.

At Track Level

The first series of measurements were made near track level to determine the horizontal component of vibration of each of the six columns due to train passages on tracks at varying distances. It was found that the results did not follow any simple law and they merit further discussion. The vibration levels for the isolated column in the 20-75 cps band were found to be slightly lower at small

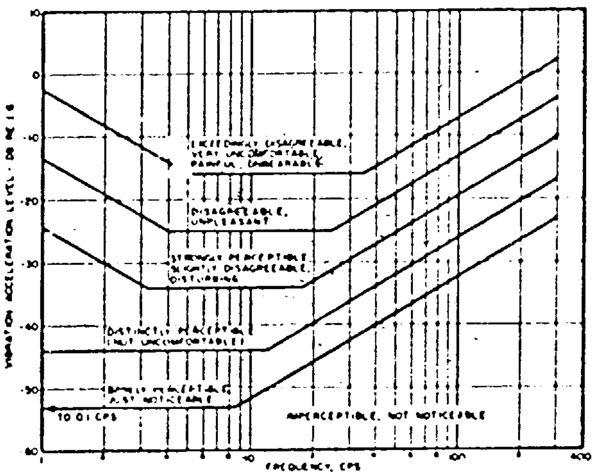


Fig. 3. Response of humans to vibrations as per BBN Figure 5.

distances and appreciably lower at larger distances than for the unisolated column. In the next higher frequency band of 75-150 cps, the vibration levels for the isolated column were slightly higher at small distances than those of the unisolated column. At the larger distances, the results were essentially the same as for the first frequency band. This result indicates that the naural frequency of the isolator pad lies in the frequency band of 75-150 cps. The isolator pads appeared to be less effective in the higher frequencies. For example, in the 150-300 cps frequency band, the difference in vibration levels was again slight for small distances and only moderate for a distance of 200 ft., in the 600-1200 cps frequency band, the differences in levels was small over the full range of distance. This was not considered to be serious on this project, since most of the energy emanating from railroad vibration is concentrated in frequencies below 300 cps and the energy contained in the higher frequency vibrations is readily absorbed in a normal building structure.

At Higher Elevations

The vertical components of vibration were next measured at higher elevations of these six columns. The vibration levels were found to be moderately lower in the 20-75 cps band, considerably lower in the 150-300 cps band and slightly lower in the 300-600 cps band, for the isolated column than for the unisolated column. These values were recorded at the first floor level above the tracks during the passage of a commuter train on Track 7; similar, but slightly lower differences were found for the passage of a diesel switcher on Track 11 at a lateral distance of 100 ft.

These results indicated that the isolator pads afforded some reduction of structure—transmitted noise and vibration. For purposes of design, the isolation of a column was assumed to afford a reduction of noise and vibration. The measurements showed an isolation effectiveness of the pad ranging from 2 db to 12 db, depending upon distance, frequency and other factors. For purposes of design on this project, an average value of 8 db was selected. The reader is cautioned against an acceptance of this value for use on other projects without further consideration. Differences in column spacing, pad composition, structural details and geometry are a few of the many factors which may give rise to variations in this numerical value.

Noise Level Computations

The forecasting of the noise level to be expected from railroad activity in any occupied space of the Development consisted of the integration of the individual effects discussed above. The integration consisted of a series of corrections to the equivalent NCA noise level given in Fig. 4 for the height of the particular space above track level. Certain noise control recommendations were included in the calculations. The recommendations were formulated during the design stages and are summarized as follows:

a) *Isolator pads.* The installation of isolator pads between the column grillages and the tops of the footings was carried out for the majority of the columns throughout the project. Studies of certain columns at large distances from tracks and supporting noisy-occupancy areas revealed the complete feasibility of omitting isolator pads at these locations and this was done.

The asbestos component of the pads installed under the Royal Bank Building took the form of cement-asbestos board. This building is essentially to one side of the higher-speed tracks. The asbestos component of those pads more directly over the higher-speed tracks took the form of fire-felt asbestos. Although the fire-felt pads are probably somewhat superior acoustically to the cement-asbestos pads, they were designed to function under compressive unit loads of 600 p.s.i. as contrasted to the 500 p.s.i. working unit loads of the latter. The loads of the tower columns, in excess of 12,000 kips, were one consideration in this choice. It should also be mentioned at this time that the exterior vertical and top surfaces of the concrete footings, the grillages and the columns to elevations above railroad platform level were encased in two one-inch-thick waterproofed layers of cork. The cork was later encased in 4-in. of protective concrete. For those footings directly below tracks, the upper surfaces of the footing and grillage were isolated with lead-asbestos pads in place of the cork.

b) *Double spring frogs.* It will be recalled that open-gap frogs were found to be the most offending component of trackage in the yard. It was recommended that three such frogs nearest the office areas be replaced by the much quieter double-spring frogs. The double-spring frogs reduce the track gap and hence the noise as the wheels pass over them. Since these frogs can swing in both directions, the reduction is valid for both directions of travel.

c) *Track Welding.* Construction with

Fig. 4. Decay of railroad noise level with height as per BBN Figure 1.

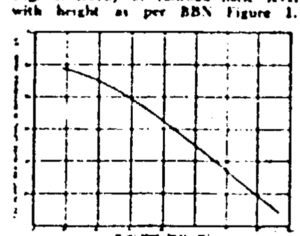
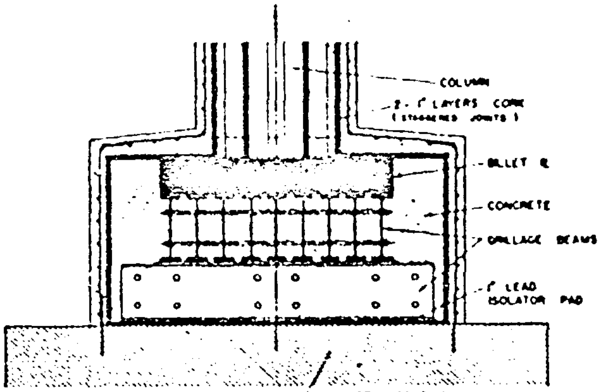


Fig. 5. Typical footing isolation details.



the measurements, the welding of straight tracks and low-curvature curved tracks was carried out throughout the yard.

d) *Project Separation.* The structural framework of the project was separated from adjacent structures to avoid the introduction of secondary paths of noise or vibration transmission. Resilient joints were provided across this separation in the way of pedestrian or vehicular crossings.

Pad Installation

The relatively flexible nature of an isolator pad made careful workmanship necessary during the planing procedure of the upper concrete surface of the footings. This was accomplished in the usual manner with a machined steel screed sliding on accurately-leveled and machined supports. Two coats of black asphaltum paint were placed on the concrete to prevent any possible chemical action between it and the lead sheath of the pad.

The magnitudes of many tower column loads gave rise to grillages of large linear dimensions. The lower grillage beams of the heaviest tower columns, for example, covered an area of approximately 9 ft. by 11 ft. Dimensions of this order resulted in the fabrication of the isolator pad in segments for all of the larger footings. The joints between the segments were sealed with industrial tape 2 in. in width to prevent the interstitial grillage concrete from forming vibration paths through them. The details of a typical installation are shown in Fig. 5.

Conclusions

The studies outlined in this paper offer a sound approach to the resolution of a complex problem. The result indicated to the designers that a satisfactory solution was achieved within the scope of normal construction procedures. It is hoped that this paper may be of use to others in this field.

Acknowledgements

The author wishes to express his deep indebtedness to Laymon N. Miller of the firm of Bolt, Beranek and Newman Inc., acoustical consultants on this project, for his painstaking work during this study and to I. M. Pei, architects, for permission to use the quoted data.