In Plant Partial Noise Enclosures for the Mining Industry

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IN PLANT PARTIAL NOISE ENCLOSURES FOR THE MINING INDUSTRY

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IN PLANT PARTIAL NOISE ENCLOSURES FOR THE MINING INDUSTRY

By

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ABSTRACT

The Physical and Toxic Agents Division of the Mine Safety and Health Administration's Pittsburgh Safety and Health Technology Center has conducted three joint noise control demonstrations at dry milling operations. These demonstrations were conducted on a rod mill, a roller mill, and a ball mill, in order to survey a representative sample of the more commonly utilized types of milling equipment. The noise control concept that was demonstrated involved the construction of partial enclosures surrounding the mills and then adding acoustical materials within the enclosures to absorb the build up of acoustical energy. The results of this work illustrate the feasibility of this concept, the physical principle of creating an acoustical shadow, and the ability to closely predict the amount of absorptive material required to reduce the noise levels so as to comply with the Code of Federal Regulations (CFR), Title 30.

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INTRODUCTION

In the material processing segment of the mining industry, minerals and ores are transformed, combined, or refined into useful products. These processes all involve some type of material size reduction or combination, which is frequently accomplished by milling. Personnel who work in close proximity to material processing and handling equipment; e.g., crushers, sizing screens, cyclones, and mills are frequently exposed to noise levels well in excess of the criterion established by the Walsh-Healy Public Contracts Act of 1969, table 1.

TABLE 1. - PERMISSIBLE NOISE EXPOSURES

NOISE LEVEL (dBA)	DURATION PER DAY (HOURS)
90	8
92	6
95	4
97	3
100	2
102	1 1/2
105	1
107	3/4
110	1/2
115	1/4 or less

The Code of Federal Regulations (CFR), Title 30, sections 56.5050, 57.5050, 70.510 and 71.805 stipulate that the implementation of feasible administrative and/or engineering controls shall be utilized to keep noise exposures below the allowable limit. Difficulties are often encountered, however, when attempting to apply retrofit noise controls to facilities that were designed and constructed long before the enactment of these federal regulations.

Typically, this type of equipment is large and is situated in plants with very high and/or partial ceilings so as to accommodate overhead obstructions such as conveyor belts, feed bins, chutes, structural supports, and catwalks. Processing plants that house such equipment are, for the most part, constructed of hard, acoustically reflective materials, e.g., corrugated sheet metal. The combination of high noise levels in this type of building creates a build-up of acoustical energy.

In addition to the individuals whose work stations are located in the near field of such equipment, maintenance personnel and others who frequently pass by are exposed to these high noise levels. As in any noise control problem there are three major components; the source (machinery), the path or paths that the noise travels (airborne and or structural) and the receiver (affected workers). In lieu of redesigning the machinery or relocating the affected workers, a feasible and effective solution is to disrupt the direct path between the source and the receiver by enclosing the noise source.

In the formulation of this type of noise control technique, one must take into account several factors such as:

1. The noise reduction required to achieved compliance with the mandated health standards.
2. The required performance and durability characteristics of the acoustical material utilized in the construction.
3. Maintenance accessibility including the possible requirement for visual inspection.
4. Ensuring that disruption of current production techniques is minimized.
5. Maintaining the employees' overall safety and welfare.
6. The cost differential of the enclosure as determined by the various construction materials and size.

ENCLOSURE DESIGN CONSIDERATIONS

In view of the aforementioned operational requirements, particularly the overhead obstructions, one of the most plausible engineering noise controls is the utilization of a partial/ topless enclosure. In designing an enclosure, the extent to which maintenance accessibility is required should be viewed in a worse possible case scenario, i.e., total removal of the enclosed equipment. Hence, the range of solutions can run the gamut from a personnel access door to a totally removable enclosure. If visual observation of the machinery is a requirement, it can easily be incorporated into the design by utilizing properly mounted and sealed windows, strategically placed mirrors, or through the use of remote television cameras. If complete access to the machinery is periodically necessary, the enclosure can be designed and constructed of interlocking, track mounted partitions which can be easily separated and slid out of the way.

Selecting the appropriate material for an enclosure is dependent upon three factors. The first is the noise reduction required, which in turn is a function of the sound transmission loss (STL) rating of the material selected. Materials such as fire retardant plywood (which may decompose within a few years, depending upon ambient temperature and humidity) or mass loaded vinyl or composite curtains are available in a variety of densities and corresponding STL ratings. The second factor to consider in selecting the type of materials is the physical constraints surrounding the machinery. These constrains dictate whether a rigid, or flexible, enclosure is more appropriate. They can be used in conjunction with each other provided an air tight overlap is provided. The third factor to consider is the relative cost of the construction materials and labor, in which the size of the enclosure is an important variable.

To achieve maximum acoustical effectiveness, it is necessary to ensure that all openings in the walls or around doors of the enclosure are tightly sealed. Vinyl curtain panels are available with mating Velcro - Velstick[2] edges, and strips of used conveyor belting can be attached to the overlapping plywood panels to form a positive seal.

A reduction in normal ventilation is expected of any enclosure system resulting in an increase of ambient temperature. This temperature increase can possibly affect the wear characteristics of the enclosed equipment and the possible degradation of the material being processed. Quality control in the milling of Portland Cement, for example, is quite temperature sensitive. Consequently, consideration for adequate ventilation may be necessary in the engineering design phase of some enclosures.

In order to optimize the noise protection afforded by a partial enclosure, it must be sufficiently high enough so as to establish an acoustical shadow zone, in which the affected employees perform their duties. Theoretically, by measuring the straight line distance from the noise source to the employees work station; by determining the predominate frequency of the noise and the required attenuation, the height of the partial enclosure can be determined, utilizing the Fresnel equation.

$$N = 2/\lambda \quad (x + y - z) \qquad (1)$$

where:
- N = Fresnel number (dimensionless)
- $x + y$ = path length over enclosure wall (feet)
- z = straight line distance between noise source and receiver (feet)
- λ = the wavelength of the predominate sound frequency, (feet)

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2 Reference to specific brands, equipment or trade names is made to facilitate understanding and does not constitute an endorsement by the Mine Safety and Health Administration.

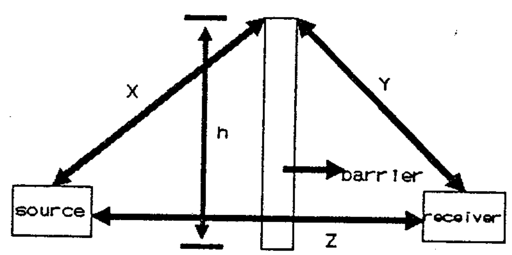
The wavelength of sound is defined as:

$$\lambda = c/f \qquad (2)$$

where: c = the speed of sound, which at 70° F is 1,128 ft/sec., (344 m/sec.) in air
f = the frequency of the predominant sound in Hertz (Hz)

This concept is diagrammatically illustrated in figure 1.

Figure 1. Parameters of Acoustic Barriers



For illustrative purposes, consider the simple symmetric case where the barrier is equidistant between the receiver and the source. Upon solving equation (1) for x + y it will be noted that $x^2 = y^2 = h^2 + z^2/4$ and that h will ultimately be defined as

$$h=\sqrt{\frac{N\lambda}{4}\left(\frac{N\lambda}{4}+Z\right)} \qquad (3)$$

However, these calculations assume a free field environment with the enclosure wall situated equidistant between the source and the receiver! Due to the multi - reverberant planes of most milling facilities and the operational constraints which may dictate the location of the enclosure wall, the effectiveness of the acoustical shadow will be greatly diminished from the theoretical predicated reduction. In such cases the available position will determine the required height of the enclosure wall. This disparity will be noted in each case study. From a practical standpoint it should be noted that in order for an enclosure/barrier wall to be effective (that is create a shadow zone) the height of it relative to the employee's ear level should be at a minimum of 30^0, as illustrated in figure 2. This will insure that the Fresnel number N is > 0 which is within the shadow zone along the x axis of figure 3.

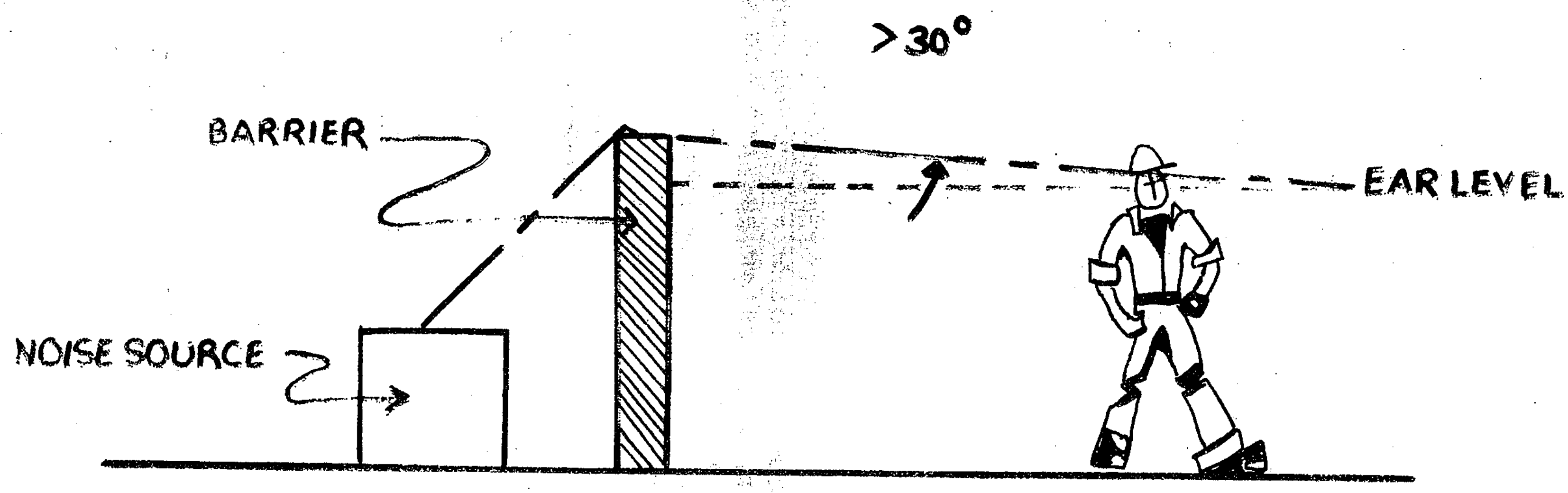


FIGURE 2 ILLUSTRATION OF 30° ANGLE NECESSARY FOR ACOUSTICAL EFFECTIVENESS

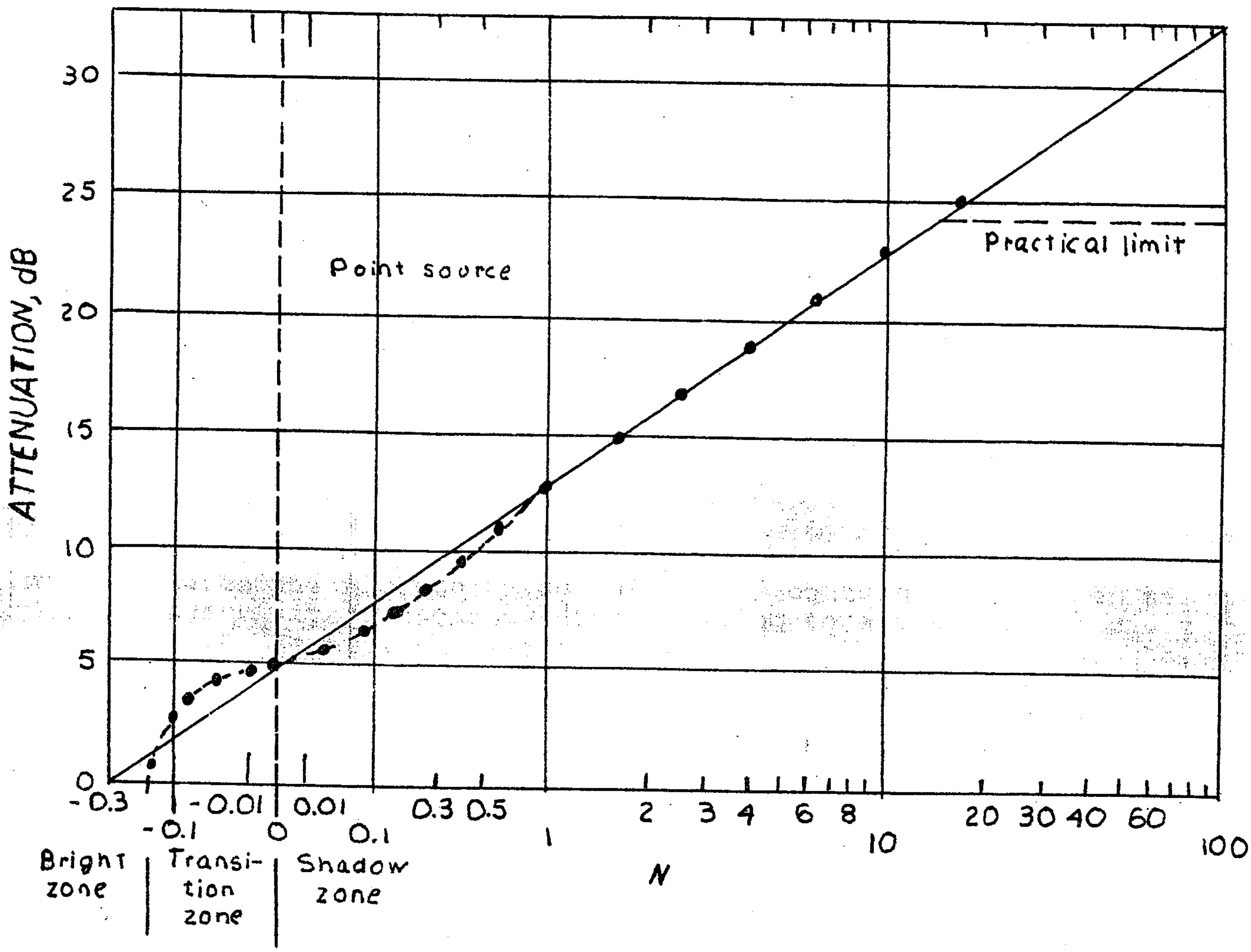


FIGURE 3 BARRIER ATTENUATION AS A FUNCTION OF FRESNEL NUMBER

As noted earlier when these design guidelines are applied to a real world situation, there are frequently many physical and operational constraints to overcome, e.g., overhead obstructions, maintenance accessibility, visual observation, input and discharge mechanisms, temperature sensitivity of the material being processed, etc. In order to ensure that the enclosure is well designed, all of the variables impacting the equipment to be enclosed and whatever operational constraints, i.e., normal flow of material through the plant, must be taken into consideration. This can best be accomplished by soliciting input from both management personnel and employees who either work in the area or perform maintenance on the equipment. The design process is <u>very crucial</u> to a successful enclosure installation.

<u>PREDICTING SOLUTIONS TO THE BUILD UP OF ACOUSTICAL ENERGY</u>

A properly designed and constructed partial enclosure can reduce employees' noise exposure only if their line of sight to the machine is interrupted. However, the acoustical energy emanating from the machine will not be reduced; it will only be redirected. Frequently, this build up is either funneled upwards to other floors of the plant, and reflected off the ceiling, or due to diffraction characteristics, the sound waves will bend over the enclosure walls toward the employee. One way to minimize the build-up of acoustical energy is through the introduction of acoustically absorptive material inside or above the enclosure.

Prior to the introduction of absorptive materials to partial enclosures, the following considerations must be addressed. First, the sound pressure levels (SPL) inside, outside, and at the top of the enclosure will need to be analyzed to determine their spectral composition. This can be accomplished preferably by real time analysis of tape recorded data, or through the use of a field octave band analyzer. This information is necessary since absorption coefficients for different acoustical materials are frequency dependent. Second, in addition to the required attenuation, consideration must be given to the durability of the material selected.

<u>Exposure to degrading elements such as heat, dust, water, oils, and solvents can severely limit the usefulness of acoustical</u> materials and possibly endanger employee safety. The selection of the appropriate acoustical material should be done with a worse case scenario in mind. Acoustical materials should, if exposed to such harsh conditions, have a protective facing that will not impede their absorption capabilities. They should also be easy to install, remove, and re-install without being damaged so that when maintenance, such as cutting or welding is required near these materials, the dangers of toxic fumes or accelerated flame-spread can be minimized. Due to these constraints written

verification of the physical characteristics of any materials utilized in a partial enclosure should be obtained prior to purchasing. Third, calculations will need to be made to determine the amount of absorptive material necessary to achieve the desired noise level reductions. All materials possess the ability to absorb sound in varying degrees. Most commonly utilized building materials and sound control materials have been tested to determine their Noise Reduction Coefficient (NRC).(3) This value ranges from 0 to 1.0, with 1.0 representing 100% absorption of all incident acoustical energy. It is the arithmetic average of a material's absorption coefficient of the four center band frequencies (250, 500, 1000 & 2000 Hz), rounded to the nearest multiple of 0.05.

The following equation is frequently utilized to estimate the effects of introducing a known quantity of absorptive material with a given Noise Reduction Coefficient (NRC)

$$NR = 10 \log \frac{A_o + A_a}{A_o} \quad (dB) \qquad (4)$$

where: NR = Sound level reduction in dB due to added absorption

A_o = Original absorption present in sabines, which is the summation of the square footage of the interior walls, floors and ceiling of an enclosure, multiplied by their respective Noise Reduction Coefficients

A_a = Added absorption in sabines.

To approximate the amount of additional absorptive material necessary to achieve the noise reduction desired, the following formula has been derived from equation (4):

$$A_a = A_o \, (10^{NR/10} - 1) \qquad (5)$$

The ratio of A_a to the Noise Reduction Coefficient (NRC) of a selected absorptive material is the theoretical number of square feet necessary to yield a desired noise reduction.

CASE STUDIES

During the past six years, the Physical and Toxic Agents Division of MSHA's Pittsburgh Safety and Health Technology Center has conducted joint noise control demonstrations at dry milling operations. The following case studies detail the methods of installation and then the measured effects of acoustically treating topless enclosures around three different types of mills. Included in these evaluations is an assessment of the baseline noise levels, the construction techniques, the predicted noise reductions due to the addition of absorptive materials and the measured noise reduction achieved.

CASE 1 - VINYL CURTAIN ENCLOSURE OF A ROD MILL

The first demonstration of this technology was conducted in a processing plant of a limestone quarry. The affected employees included baggers, mill operators and maintenance personnel all whom worked in the immediate area surrounding a rod mill. A floor diagram indicating the locations at which the baseline acoustical measurements were taken and the location of the enclosure is illustrated in figure 4. The tape recorded measurements were subsequently analyzed for spectral composition and overall dBA sound levels, the results of which are listed in table 2.

An evaluation of the existing superstructure was made to determine the most advantageous location to suspend an approximately 16 ft. x 20 ft. (4.9 m x 6.1 m) rectangular frame of channel track from which the enclosure was hung. Suspension of this frame was accomplished by: cutting and welding to existing supports, and/or through the utilization of varying lengths of 1 ton (907.2 kg) capacity link chain. The framework was hung level to insure that the enclosure would form a positive seal with the floor. Hooks were installed into the channel track and the sections were joined together with 90° corner fittings. With the framework in place, work began on hanging a barrier curtain in sections, which were 52 in. wide by 16 ft. long (1.3 m x 4.9 m) with a density of 3/4 lb/ft.^{2} (3.7 kg/m^2). For the most part, this was merely a matter of hooking the grommeted curtain over the hooks in the channel track. However, some cut and fit work was necessary to insure access to the charge and discharge ends of the mill, and the entrance to a stairway that went along side and over the mill. The individual curtain sections were joined together by two methods. The first used a Velcro to Velstick system along the length of the panels that required access for frequent maintenance, figure 5. The second method utilized nylon nuts, washers and bolts, and was used in areas where only occasional access was needed. Upon completion of the installation of the enclosure, tape recorded noise measurements were made in the same locations to assess the results of the barrier. The analyzed results of these measurements are listed in table 2. The average baseline noise level at bagging stations 1 through 4 was 99.1 dBA. The installation of the vinyl curtain enclosure reduced these levels by an average of 2.3 dBA to 96.8 dBA. Based upon the previously discussed theory, which assumes an equidistant barrier location in a free field environment, a reduction of 23 dB could have been obtained by its insertion. To help absorb the build up of acoustical energy inside the enclosure, approximately half, or 500 ft.^{2} (152 m^2), of the interior surface area was covered with a two-inch thick fiberglass blanket material, figure 6. It was installed by simply lacing the existing curtain hooks through the grommeted edges of the blanket material.

The theoretically predicted Noise Reduction in **dBA** was calculated as follows:

The original absorption A_o present within the 20 ft. long x 16 ft. wide x 16 ft. high (6.1 m x 4.9 m x 4.9 m) enclosure is the product of the surface area of the walls, floor and ceiling and their respective absorption coefficients at the 125, 250, 500, 1000, 2000, and 4000 Hz center band frequencies. The absorption coefficients were derived from established test results.(6) The following is a sample calculation at the 500 Hz center band frequency.

	Surface Area		Noise Reduction Coefficient At 500 hz		
Walls,	1152 ft.^{2} (350.2 m^2)	x	.05	=	57.6 sabins
Floor,	320 ft.^{2} (97.3 m^2)	x	.015	=	4.8 sabins
Ceiling,	320 ft.^{2} (97.3 m^2)	x	.01	=	3.2 sabins
			A_o	=	65.6 sabins

The added absorption A_a was likewise calculated by multiplying its surface area by its noise reduction coefficient.

	Surface Area		Noise Reduction Coefficient At 500 hz		
Fiberglass	500 ft. ^{2}(152 m^2)	x	.88	=	440.0 sabins
			A_a	=	440.0 sabins

By inserting the resultant values for each of the six center band frequencies into Eq. 4 a theoretical Noise Reduction was calculated. These reductions were then 'A' weighted and acoustically added. The additional theoretical Noise Reduction was calculated to be 12.2 **dBA.** Upon installation of the absorptive material the measured additional reductions at the employees' work stations was an average of 6.2 dBA, which is 6 dBA less than the theoretical predicted noise reduction.

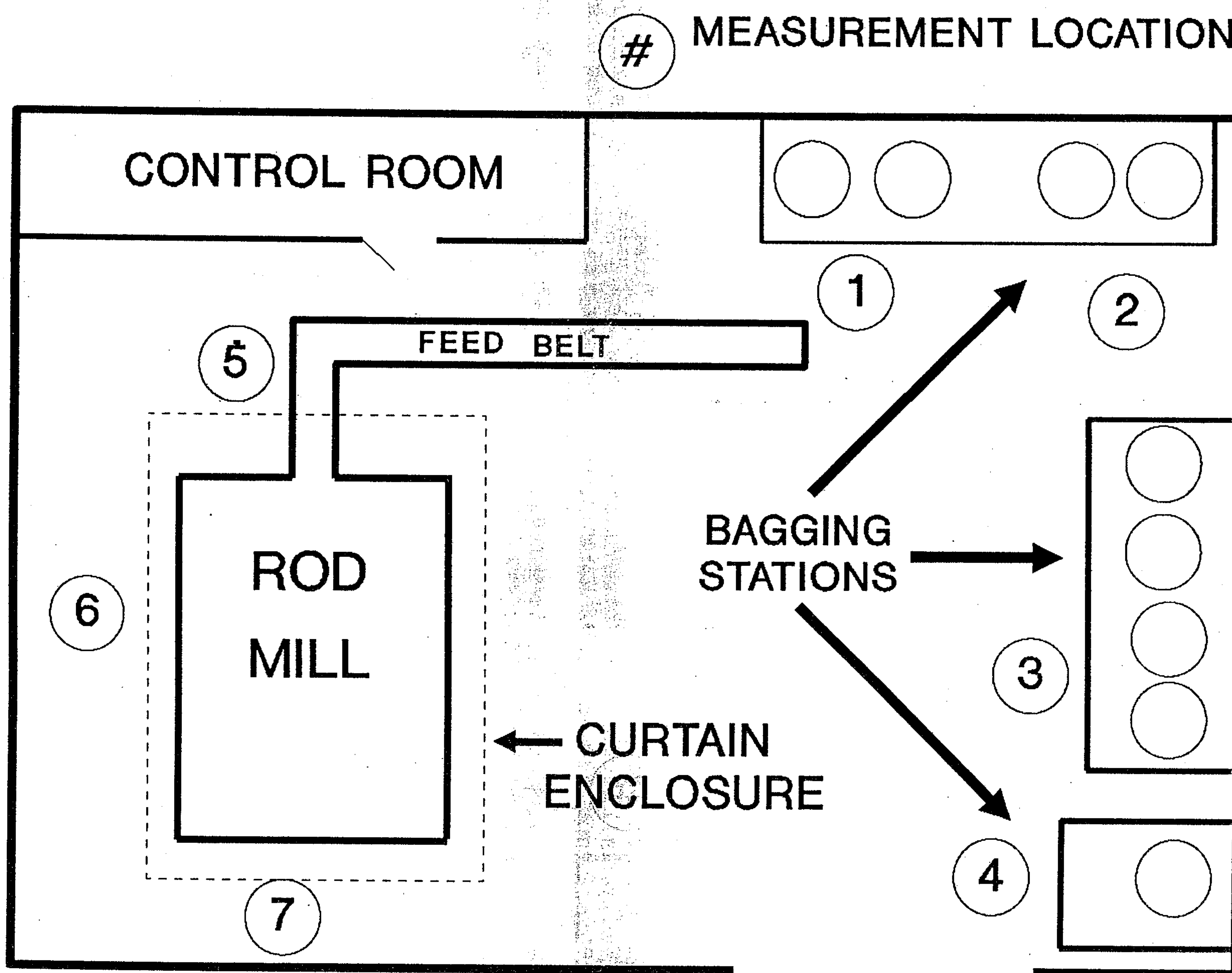


FIGURE 4 FLOOR DIAGRAM OF MEASUREMENT LOCATIONS

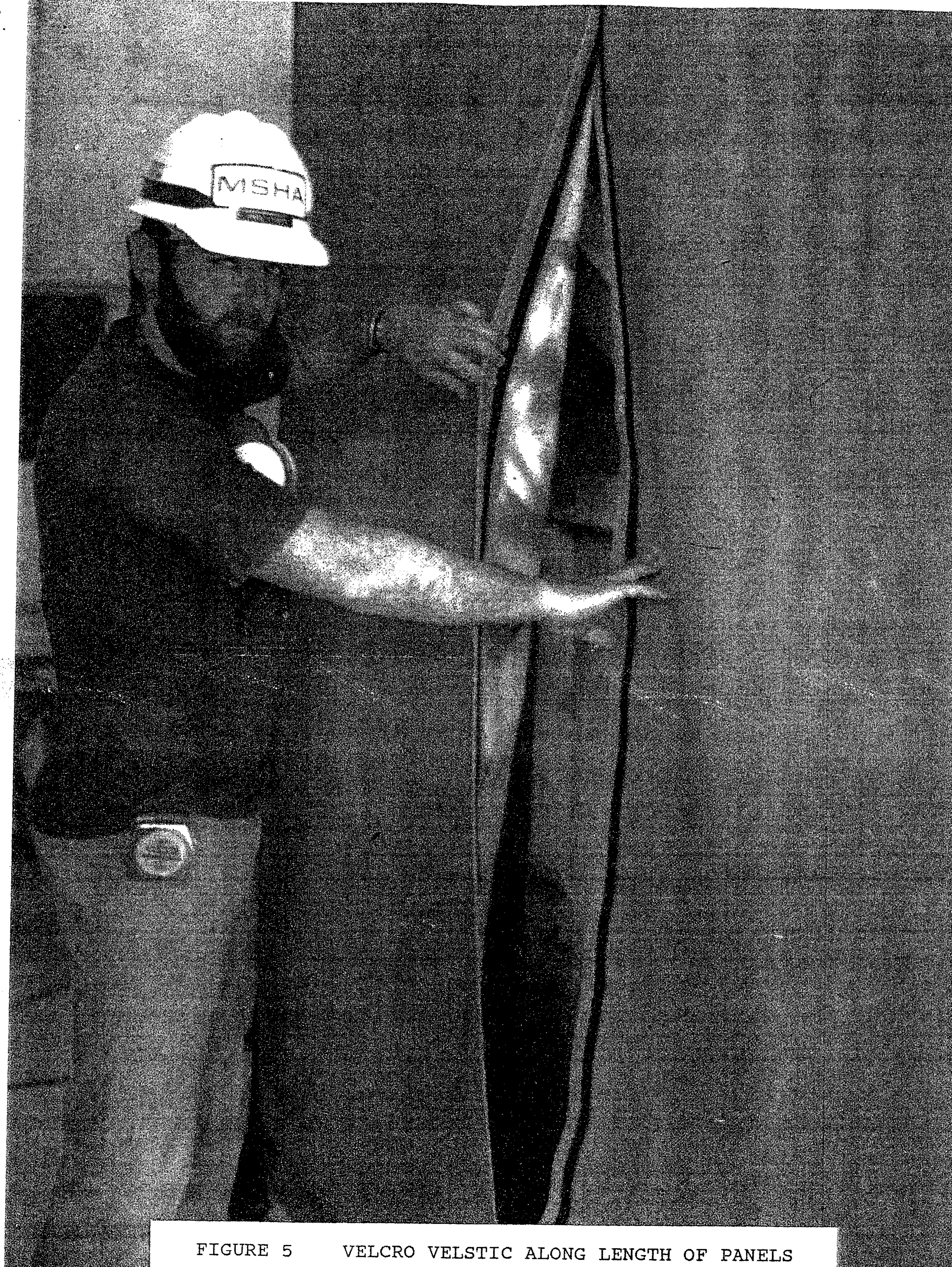


FIGURE 5 VELCRO VELSTIC ALONG LENGTH OF PANELS

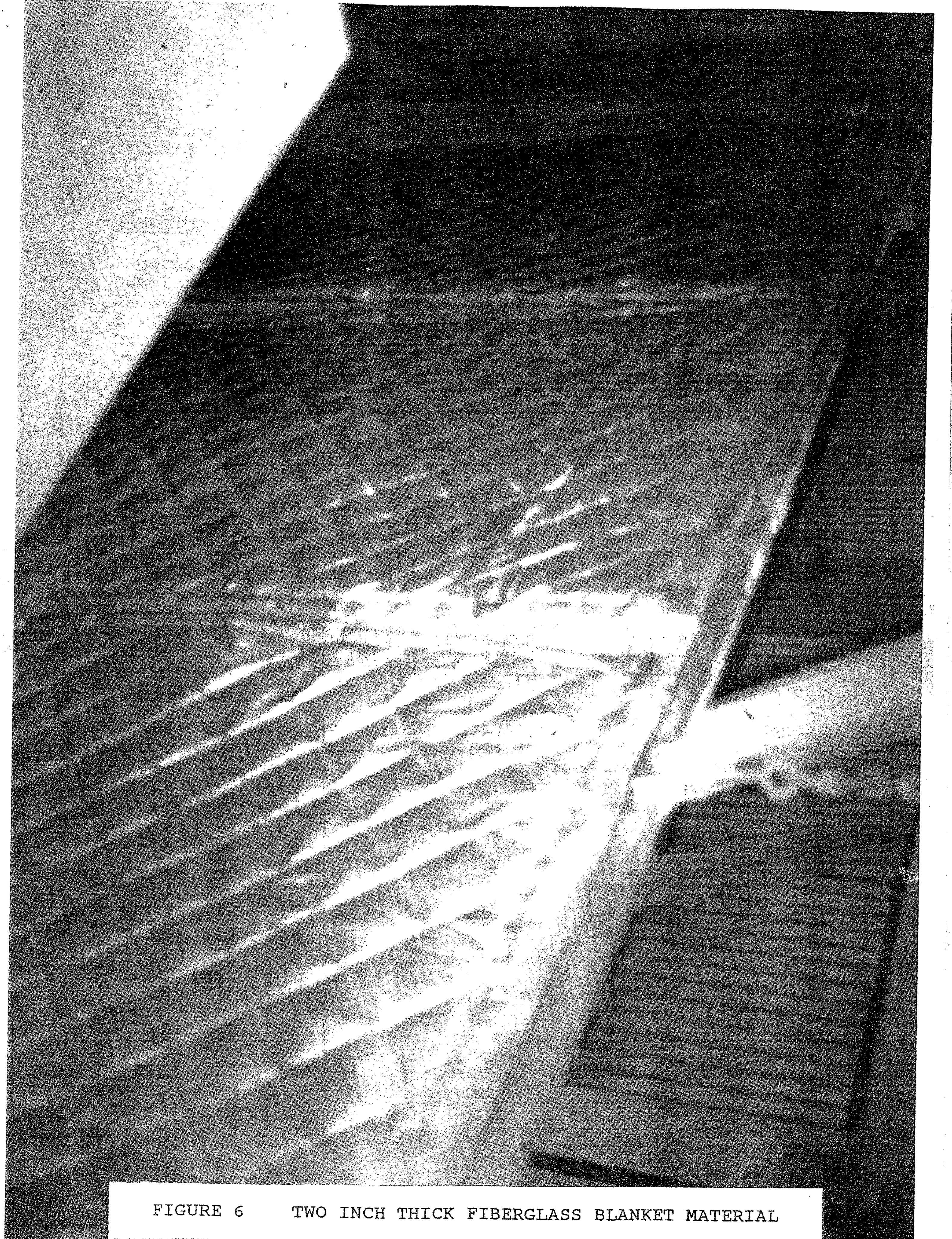


FIGURE 6 TWO INCH THICK FIBERGLASS BLANKET MATERIAL

TABLE 2 - RESULTS OF ENCLOSURE AND ACOUSTICAL TREATMENT (dBA)

POSITION	BASELINE	ENCLOSURE ONLY	ENCLOSURE WITH FIBERGLASS BLANKET	OVERALL NOISE REDUCTION
Bagging Station #1	100.0	97.5	91.2	8.8
Bagging Station #2	99.2	96.2	90.5	8.7
Bagging Station #3	99.0	97.0	90.5	8.5
Bagging Station #4	98.5	96.5	89.8	8.7
Charge End of Mill	101.8	99.5	93.8	8.0
Wall Side of Mill	107.5	100.2	94.0	13.5
Discharge End Mill	101.0	98.5	94.5	6.5

CASE 2 - PLYWOOD AND VINYL CURTAIN ENCLOSURE OF A ROLLER MILL

The second noise control demonstration was conducted in an agricultural limestone plant. There the affected employees bagged hydrated lime at stations which were eleven feet away from two roller mills. Upon reviewing the results of the acoustical investigation and following meetings with company officials, maintenance and bagger personnel, a design was conceived to utilize a topless enclosure. The enclosure took in account all operational constraints, as well as providing limited protection to not only the baggers but the mill operator and maintenance personnel who traversed the general area during the course of a shift. The 12 ft. (3.7 m) high enclosure was primarily constructed of 3/4 in. (1.9 cm) inter-connected plywood panels. In order to facilitate maintenance accessibility, these panels were suspended from sections of barn track on associated rollers, figure 7. Strips of used conveyor belting 4 in. (10.2 cm) were attached to the bottom of these panels in order to provide a tight seal with the floor while ensuring their mobility, figure 8. In areas where more frequent access to the mills was required, vinyl curtain panels were suspended from channel track. The panels were composed of polyester reinforced vinyl with a density of 3/4 lb/ft. ^{2} (3.7 kg/m^2) with 2 in. (5.1 cm) of fiberglass absorptive blanket material laminated on the inside. The 4-1/2 ft. (1.2 m) wide by 12 ft. (3.6 m) long panel sections were joined together utilizing a Velcro to Velstick system along their length, figure 9. These curtain panels overlapped the plywood panels so as to make a positive seal.

The basic configuration of the roller mills, the enclosure, and the bagging stations is illustrated in figure 10. Table 3 shows the effectiveness of the installation of the partial enclosure as measured at bagging stations number 1 and 2.

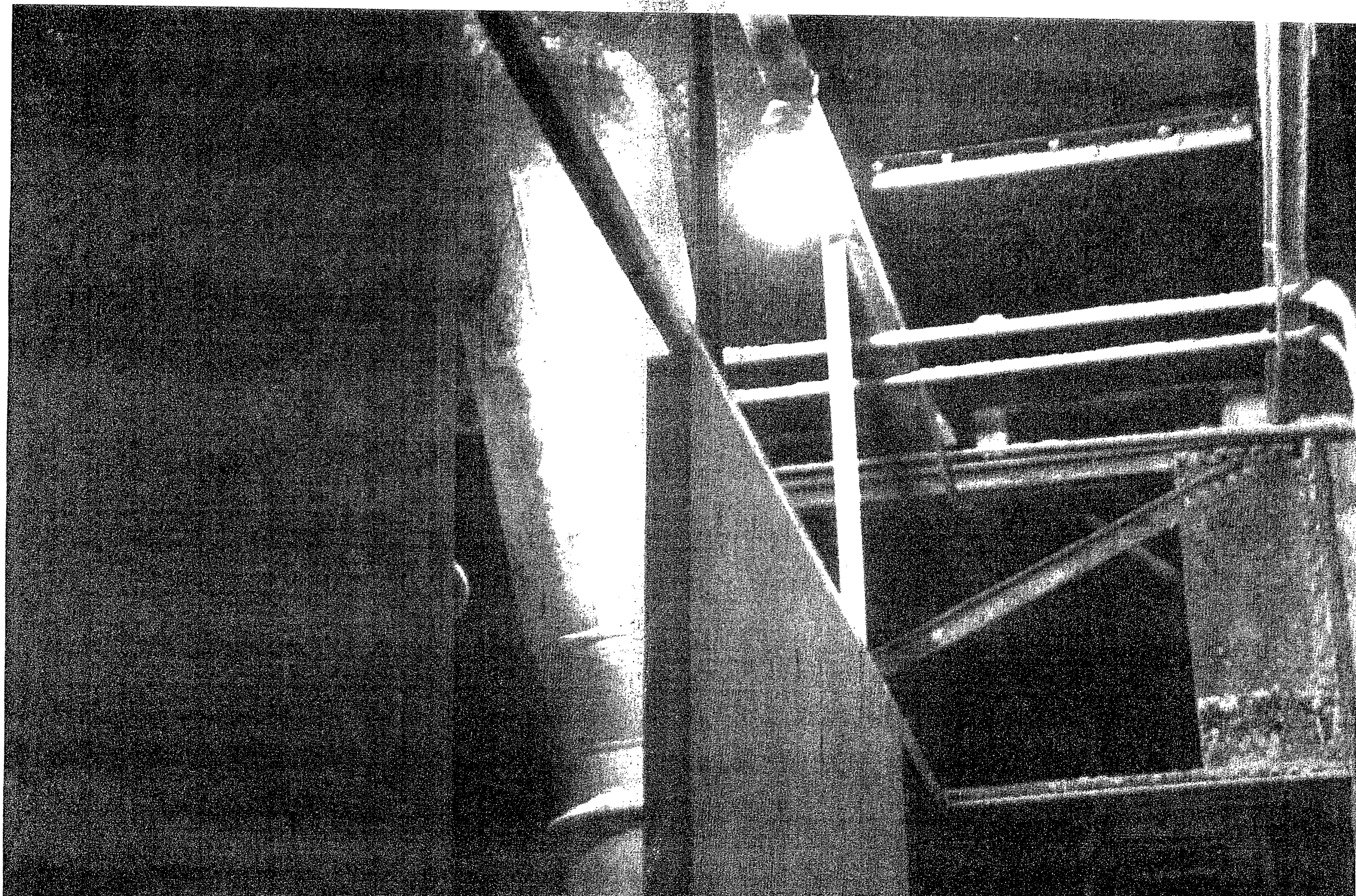


FIGURE 7 PLYWOOD PANELS SUSPENDED FROM BARN TRACK

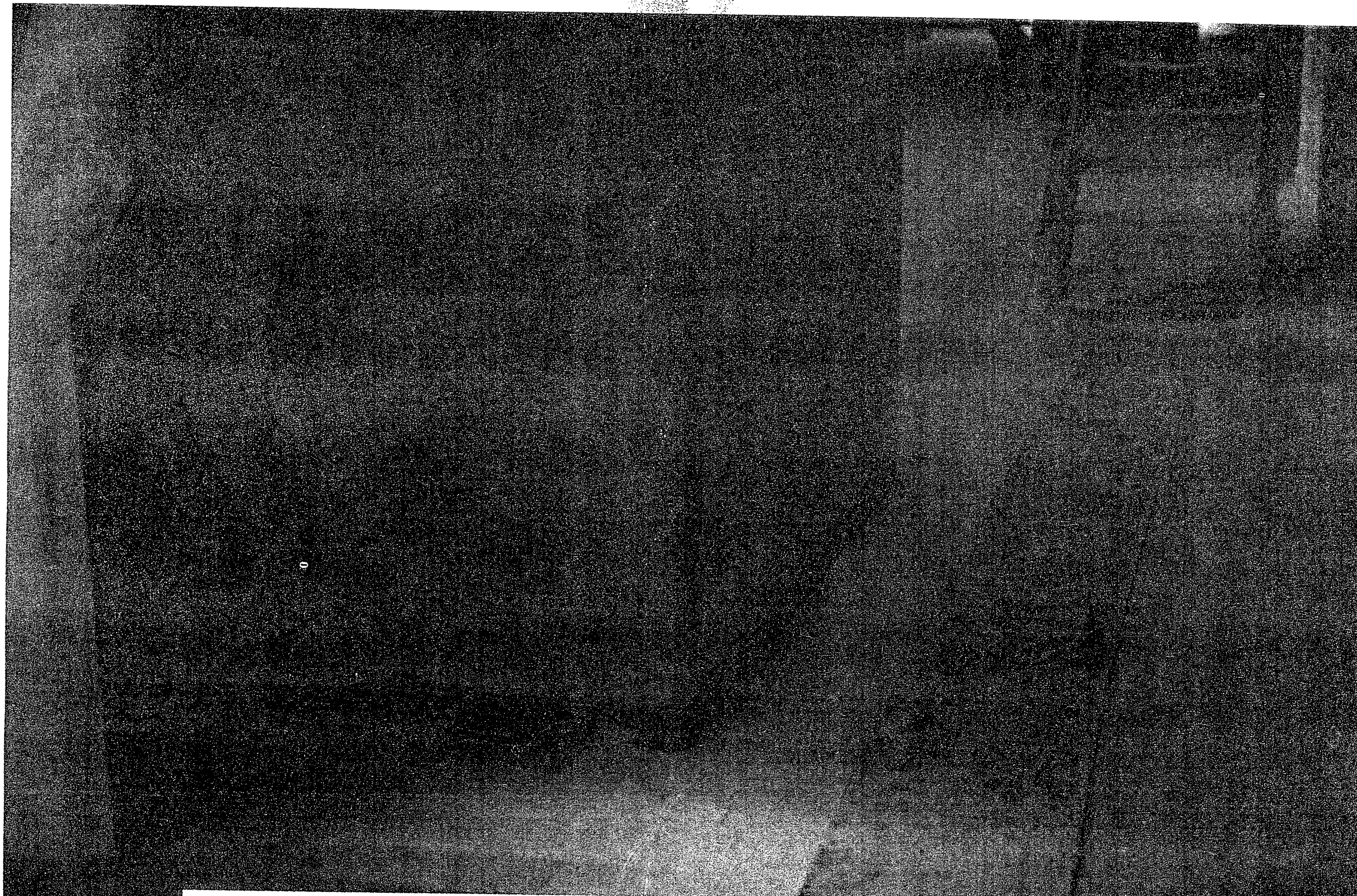


FIGURE 8 CONVEYOR BELTING ATTACHED TO BOTTOM OF PLYWOOD PANELS TO PROVIDE POSITIVE SEAL WITH FLOOR

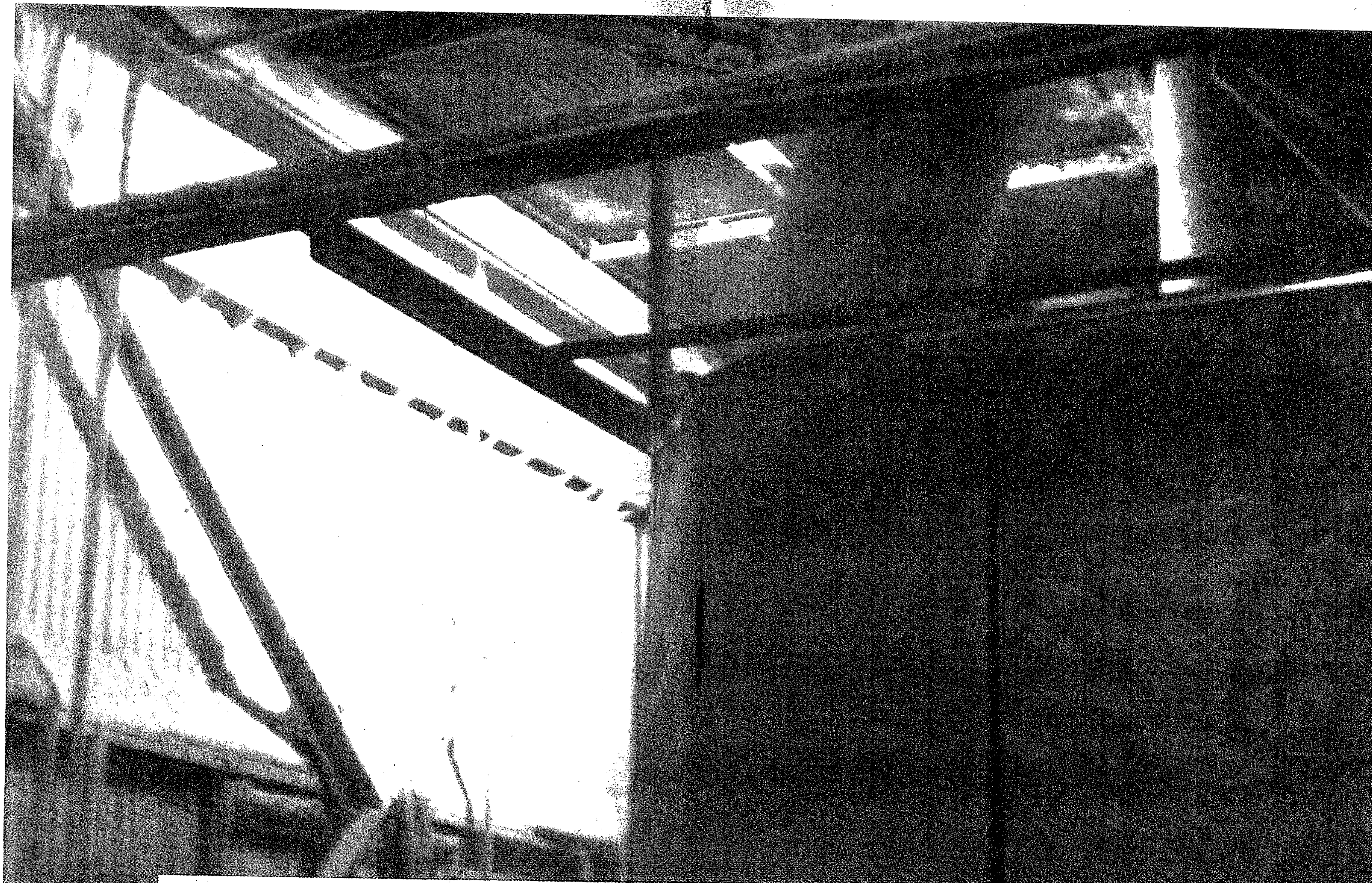


FIGURE 9 - COMPOSITE PANELS OF VINYL CURTAIN AND FIBERGLASS BLANKET MATERIAL

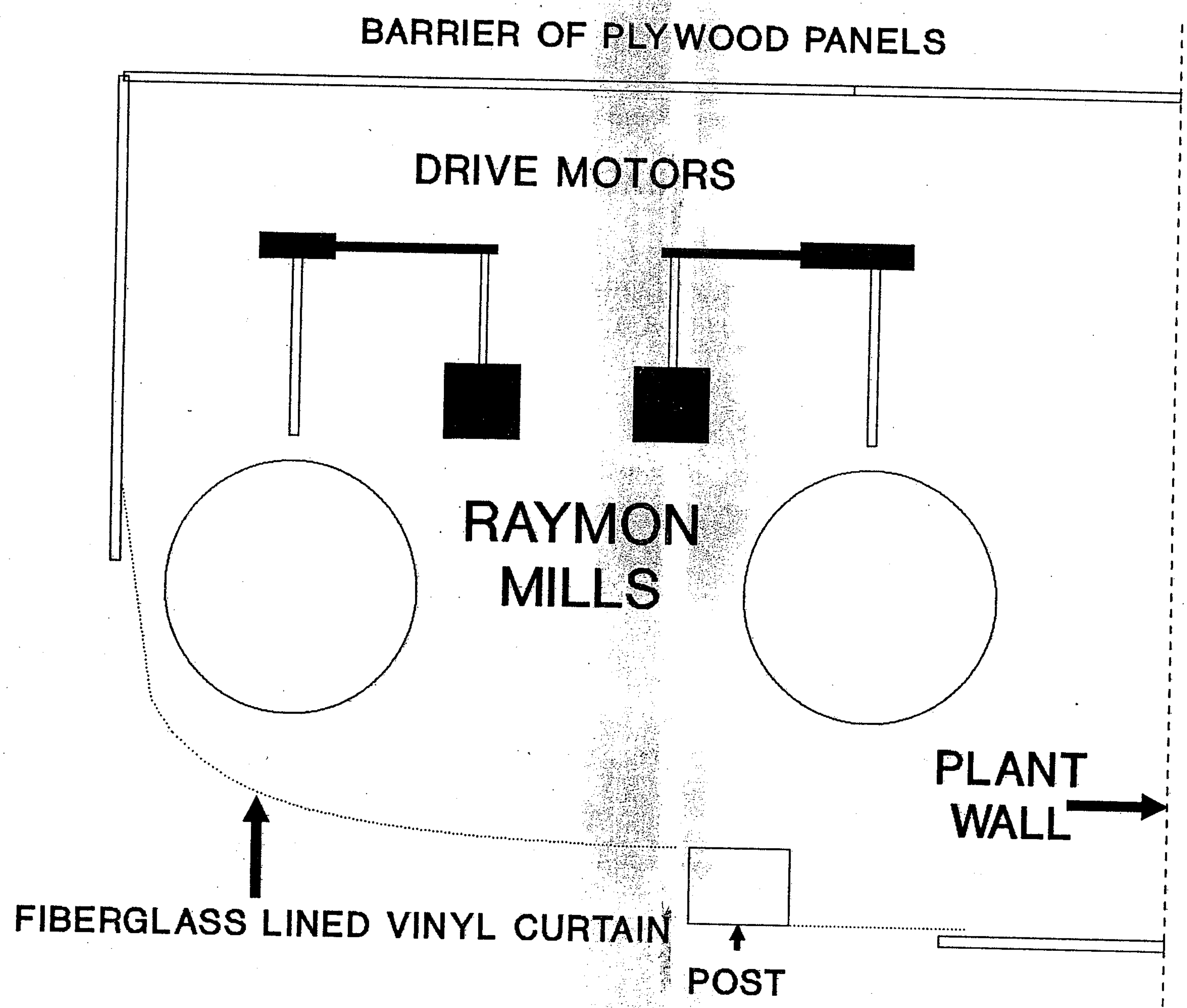


FIGURE 10 CONFIGURATION OF ROLLER MILLS AND ENCLOSURE

TABLE 3 - EFFECTIVENESS OF ROLLER MILL ENCLOSURE

LOCATION	AVERAGE SOUND LEVELS BEFORE ENCLOSURE dBA	AVERAGE SOUND LEVELS AFTER ENCLOSURE dBA	OVERALL REDUCTION dBA
BAGGING STATION NUMBER 1	97.8	85.8	12.0
BAGGING STATION NUMBER 2	96.0	85.5	10.5

Although the sound levels at the bagging stations were well below the 90 dBA level required for compliance under the Walsh-Healy Act, they represented the optimum operational condition of the roller mills, as they had been recently overhauled. Experience has shown that as the mills began to wear, there will be an increase in the overall sound level. In an attempt to further reduce the existing sound level, 90 acoustical baffles were suspended above the enclosure to absorb the sound that was being directed up and diffracted over the top of the enclosure. The 2 ft. by 4 ft. by 1-1/2 in. (.6m by 1.2m by 1.3cm) baffles were grommeted on two corners and covered with a polyethylene facing. They were suspended from galvanized aircraft cable, utilizing a wire hook through the grommets, in an egg-carton array, figure 11. The aircraft cable was attached to the plywood walls of the enclosure by means of a hook/turnbuckle assembly, and was secured with wire nuts, figure 12. Equation 4 was utilized to calculate a theoretically predicited noise reduction of 10.8 dBA. Analysis of the tape recorded measurements after the installation of the baffles showed a measured reduction of 4.6 dBA at bagging station #1 and 4.4 dBA at bagging station #2. Table 4 lists the results of the installation of these baffles.

TABLE 4 - ADDITIONAL SOUND REDUCTIONS ACHIEVED BY INSTALLATION OF BAFFLES

LOCATION	AVERAGE SOUND LEVELS BEFORE BAFFLES dBA	AVERAGE SOUND LEVELS AFTER BAFFLES dBA	OVERALL REDUCTION dBA
BAGGING STATION NUMBER 1	85.8	81.2	4.6
BAGGING STATION NUMBER 2	85.5	81.1	4.4

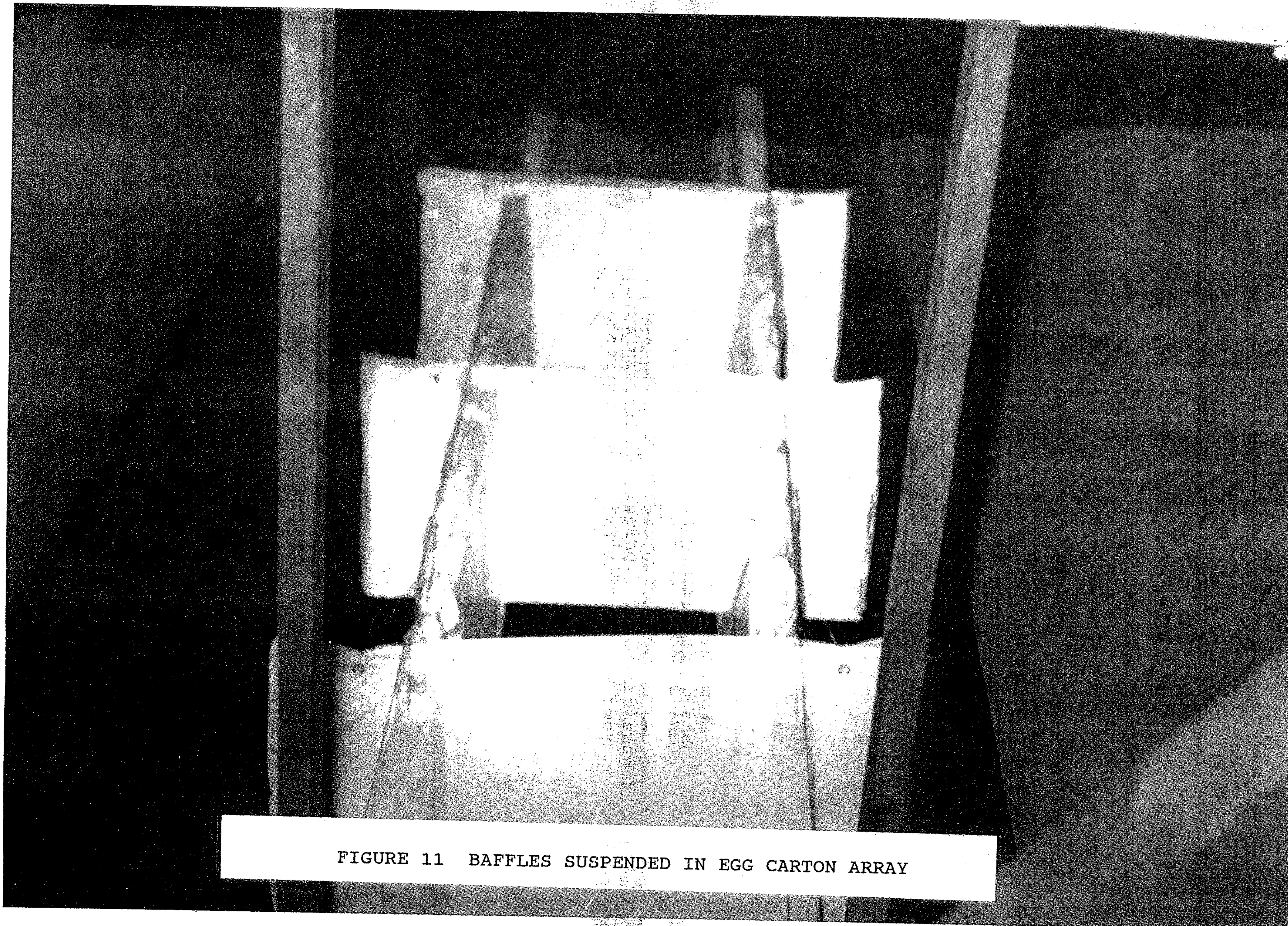


FIGURE 11 BAFFLES SUSPENDED IN EGG CARTON ARRAY

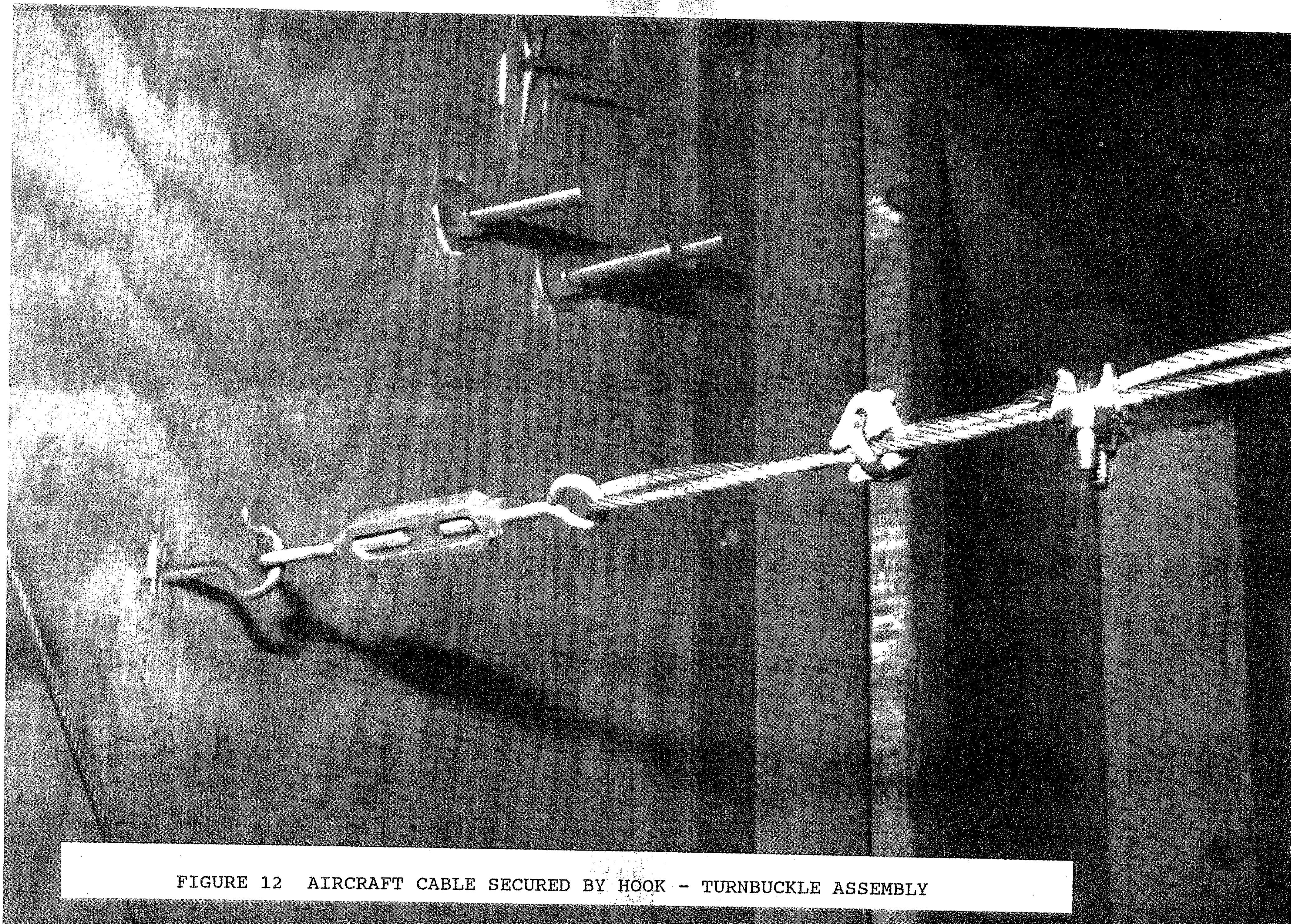


FIGURE 12 AIRCRAFT CABLE SECURED BY HOOK - TURNBUCKLE ASSEMBLY

CASE 3 - PLYWOOD ENCLOSURE OF TWO BALL MILLS

The third noise control demonstration was conducted in a magnetite milling/bagging facility. A floor diagram labeling the locations at which the noise measurements were taken is illustrated in figure 13. Upon completion of a thorough acoustic investigation, the results were discussed with the company and an agreement was reached to construct a partial enclosure separating two active ball mills from the effected employees.

The enclosure design took into account all existing operational constraints, maintenance requirements and the physical and acoustical characteristics of plywood and fiberglass baffles that would be utilized in its construction. The final design called for a three sided structure 18 ft. (5.5 m) high and approximately 30 ft. (9.1 m) on each side abutting an existing building wall. The 1/2 in. (1.3 cm) thick plywood panels were supported on 2 in. by 4 in. (5.1 cm by 10.2 cm) studs. They were constructed in 4 ft. by 8 ft. (1.2 m. by 2.4 m) and 4 ft. by 10 ft. (1.2 m by 3 m.) sections. Two sets of barn track rollers, figure 14 were attached to each of the panels. These provided an adjustable method of suspension as well as meeting the requirements for maintenance accessibility. The rollers were fitted into barn track that had been welded to the structural steel frame work which was erected by the company. The front wall presented a unique problem, in that it required two openings through which a large hopper needed to pass through so that the ball mills could be recharged three to four times a year. To accommodate this requirement, an angle iron frame work was welded to existing supports to which the plywood was cut and bolted. Overlapping doors were constructed and hinged to the plywood barrier, figure 15. Upon completion of the construction of the enclosure, a second set of noise measurements were taken to assess its effectiveness; the results of this assessment are listed in table 5.

TABLE 5 - NOISE REDUCTIONS ACHIEVED FROM ENCLOSURE INSTALLATION

LOCATION	AVERAGE SOUND LEVELS BASE LINE dBA	AVERAGE SOUND LEVELS AFTER ENCLOSURE dBA	OVERALL REDUCTION dBA
Bagger's,Station	98.2	94.6	3.6
Top of Stairs	105.0	98.0	7.0
Side of Mill	101.0	94.6	6.4
Middle of Floor	93.8	92.1	1.7

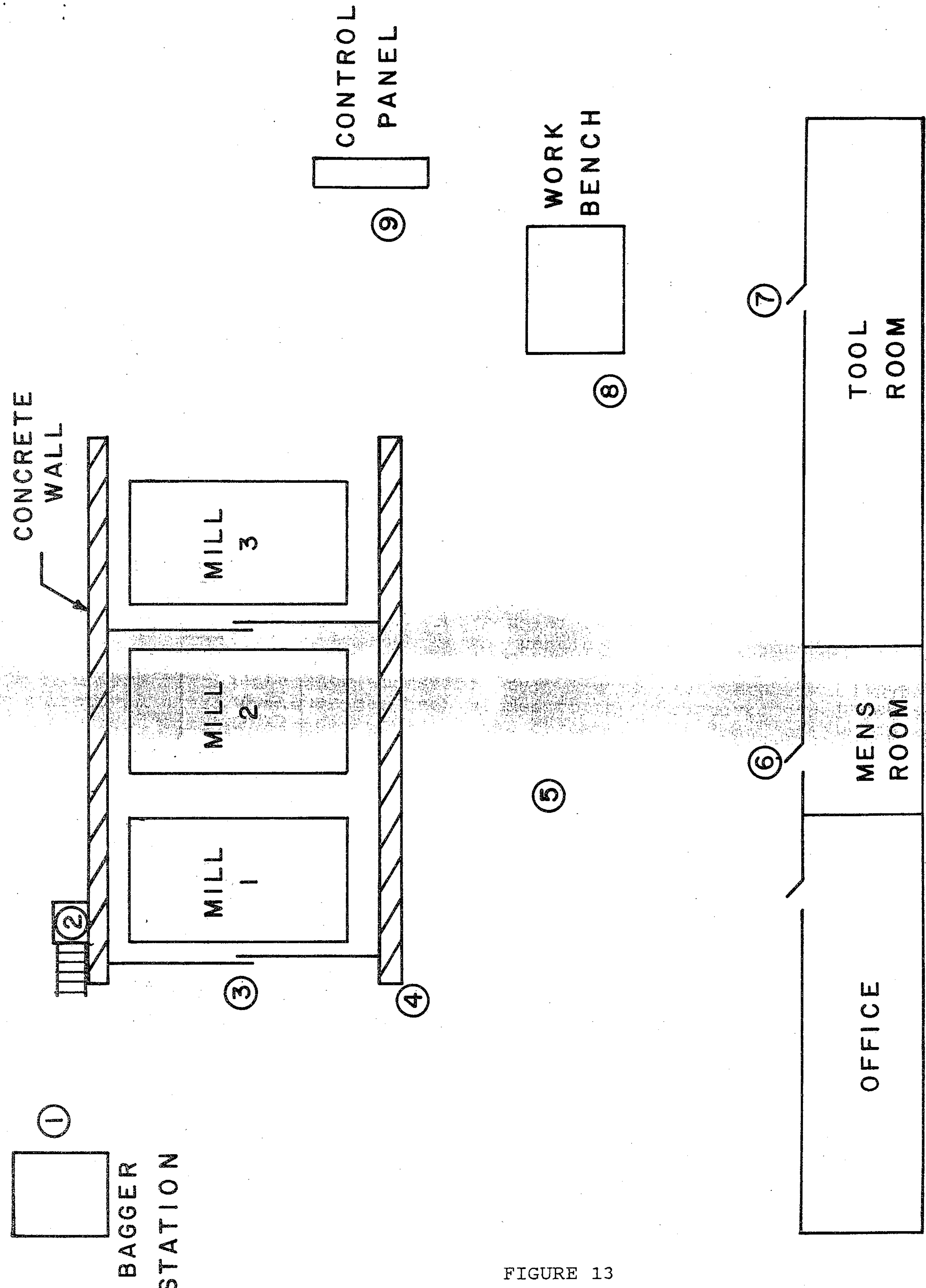


FIGURE 13
FLOOR DIAGRAM ILLUSTRATING MEASUREMENT LOCATIONS

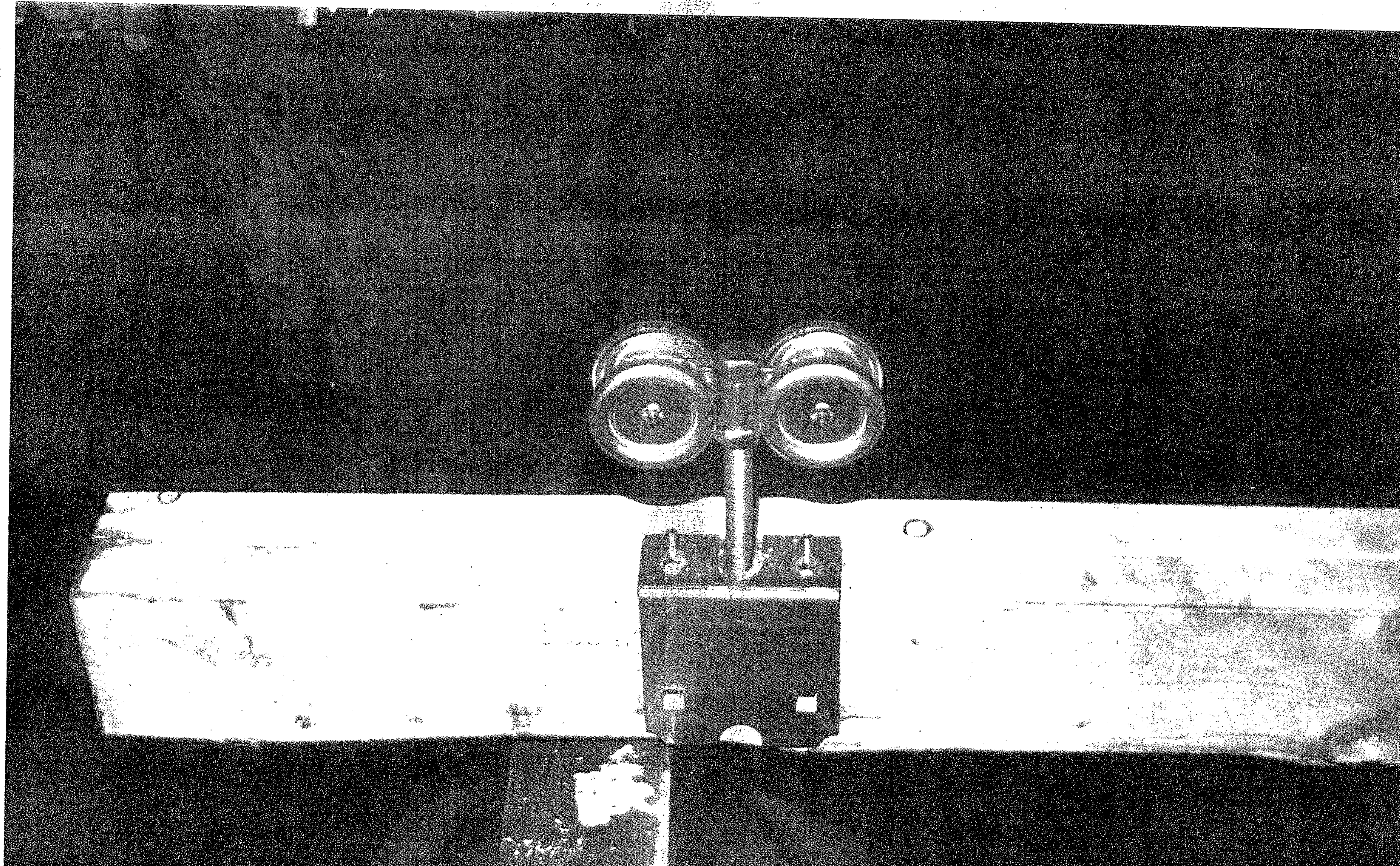


FIGURE 14 ILLUSTRATION OF BARN TRACK ROLLERS

FIGURE 15 ACCESS DOOR IN ENCLOSURE WALL

The second phase in this experimental noise control project was to install and measure the effectiveness of hanging acoustical baffles within the confines of the enclosure. The baffles were once again suspended from galvanized aircraft cables, which were drawn taut with hook and eye turnbuckle assemblies. The cables were strung length-wise over the mills, approximately 3 ft. (.9 m) apart. Utilizing wire "S" hooks through the grommeted holes in the corners of the baffles they were suspended in an egg carton array. In order to assess the predicted effectiveness of the baffles, they were installed increments of 40, after each a set of tape recorded noise samples were made at the nine designated locations shown in figure 13. Table 6 lists the resultant reductions.

TABLE 6 - AVERAGE NOISE LEVEL (dBA) VERSUS NUMBER OF BAFFLES

	NUMBER OF BAFFLES					
LOCATION	40	80	120	160	200	240
1. Bagger Station	93.0	91.5	91.2	92.0	90.2	91.0
2. Top of Stairs	96.5	95.5	95.8	96.2	94.5	95.5
3. Mid Mill # 1	93.5	92.8	92.0	93.0	91.2	91.8
4. Corner Mill # 1	91.8	91.0	90.5	91.5	90.0	89.8
5. Mill Floor	91.8	91.2	90.2	90.8	88.8	88.5
6. In Front of Men's Room	91.0	89.5	89.2	89.8	87.5	87.2
7. In Front of Tool Room	90.5	89.2	89.2	89.2	87.5	87.5
8. Work Bench	92.0	90.8	90.2	90.8	88.0	88.0
9. Control Panel	92.5	91.8	92.2	91.8	88.2	89.5

In analyzing the data contained in table 6, there is a definite reduction in the noise levels between the installation of 40, 80, and 120 baffles. However, between 120 and 160 baffles a slight elevation of these levels occurred. The most likely cause of which was the amount of magnetite present in the mills at the time the tape recordings were made. There was a noticeable reduction between 160 to 200 baffles and then a very slight rise between 200 to 240 baffles.

Table 7 provides a comparison of five selected locations throughout the plant. It illustrates the overall effectiveness of this final mill enclosure project.

TABLE 7 - COMPARISON OF NOISE LEVELS (dBA) AT SELECTED LOCATIONS DURING STAGES OF ENCLOSURE CONSTRUCTION

	NOISE LEVELS, (dBA)			
LOCATION	BASE LINE	PLYWOOD ENCLOSURE	BAFFLES INSTALLED	OVERALL REDUCTION
1.Bagger's Station	98.2	94.6	91.0	7.2
2.Mid Mill # 1	101.0	94.6	91.8	9.2
3.Top of Stairs	105.0	98.0	95.5	9.5
4.Mill Floor	93.8	92.1	88.5	5.3
5.Front of Men's Room	92.8	92.1	87.2	5.6

The overall noise reductions achieved through this noise control demonstration are very significant. The amount of time that baggers can work at their work station and remain in compliance with CFR Title 30 has increased from 2-1/2 hours to 7 hours per day. In addition the noise levels throughout the facility were effectively lowered while maintenance requirements and operational constraints were unaffected. Due to the necessity to occasionally remove/replace a large electric drive motors a complete enclosure was not possible. Therefore, no valid value could be established for the amount of absorption originally present, A_0. As a consequence, the theoretical Noise Reduction could not be calculated in this demonstration.

CONCLUSIONS

This project has demonstrated that enclosures can be designed and constructed for the mining industry. It has been shown that they are acoustically effective, economically feasible and do not hinder safety or production. There is no reason why the concepts described cannot be applied to other large machinery installations or industries. In addition these three noise control demonstrations have illustrated:

1. The use of partial enclosures around material processing equipment.
2. The use of various materials in the construction of partial enclosures.
3. The use of diffractial theory to create acoustical shadow zones.
4. The ability to closely predict the amount of acoustical attenuation afforded by the insertion of a given amount of absorptive material with a specific absorption coefficient.
5. The fact that operational and maintenance considerations can be taken into account in the basic design of enclosures so as render them functional.
6. That enclosures do fall into the realm of feasible engineering controls and can be utilized to comply with the prescribed maximum noise exposure levels as defined by the Code of Federal Regulations (CFR), Title 30.

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