NOISE BARRIERS ADJACENT TO INTERSTATE ROUTE 95
IN PHILADELPHIA, PENNSYLVANIA

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ABSTRACT

This history of Pennsylvania's first major noise barrier project, from inception to the later stages of construction, is described in detail. Construction of the barriers, which will total approximately 9,300 m^2 (100,000 $ft.^2$) was mandated by the terms of a 1975 Consent Decree signed by the Pennsylvania Department of Transportation, the U.S. Department of Transportation's Federal Highway Administration, the City of Philadelphia, and a coalition of local community groups.

Final barrier locations, types, and sizes were determined only after extensive community participation. In several instances, tradeoffs of barrier height for view of the historic Philadelphia waterfront were made. Barrier heights range from 2.4 m (8ft.) to 8.2 m (27ft.). Cost vary from $237/$m^2$ ($22/$ft.^2$) to $912/$m^2$ ($85/$ft.^2$). Noise attenuation at ground level observation points is expected to range from 6 to 15 dBA with the completed barriers.

This report includes discussion of the project's history, funding problems and implications, barrier analysis techniques, barrier design and community participation implications, barrier costs, and observation of the overall process.

INTRODUCTION AND HISTORY

Within eastern Pennsylvania, the Delaware Expressway (Interstate Route 95) extends in a north-south direction generally paralleling the Delaware River for approximately 80 kilometers (50 miles).(See Figure 1). All but a 6.4 km (4 mile) section in the vicinity of Philadelphia International Airport, which has been delayed by environmental problems, is open to traffic. A 4.8 kilometer (3 mile) section of I-95 in Center City Philadelphia was completed in the Spring of 1979, but its opening to traffic was delayed until late August, 1979 by conditions of a consent decree signed in December of 1975. (See Figure 2)

The 1975 Consent Decree was an agreement between the Pennsylvania Department of Transportation, the Federal Highway Administration (FHWA), the City of Philadelphia, and an organization called the Neighborhood Preservation Coalition (NPC) The NPC is an organization of approximately twenty constituent community groups in the vicinity of I-95 in the City of Philadelphia.

The Consent Decree required, among other things, that noise barriers be constructed, where feasible, prior to making the Center City portion of I-95 operational. It is also required that barrier designs be acceptable to the NPC.

Prior to the signing of the Consent Decree, the Department had performed noise monitoring and preliminary noise prediction analyses. Under the terms of the Consent Decree, the Department was required to obtain the services of an independent noise consultant to verify the preliminary analyses and to determine recommendations regarding feasible noise barrier types and locations. A consultant was retained and, after considerable delays, published a final noise report in December, 1977. The report verfired previous analyses performed by the Department and recommended various abatement treatments. Upon review by the NPC and the Department, the report's solutions were found to be generally unacceptable. Many of the suggested barriers obstructed the adjacent communities's view of the Delaware River waterfront while other abatement recommendations (such as building insulation and air conditioning) presented legal and long-term complications as well as being contrary to the terms of the Consent Decree.

Following the rejection of the consultant's recommendations, the Department and the NPC initiated a series of meetings with the intent of ultimately arriving at an acceptable solution which would provide the optimum in terms of both noise reduction and view. It was through approximately 30 such meetings, and two large formal public meetings, that the final determinations of barrier locations, sizes and types were resolved.

The following sections review the barrier design and community participation processes from the initiation of detailed community discussions through the later phases of barrier construction.

BARRIER FUNDING PROBLEMS AND IMPLICATIONS

About a year after the signing of the Consent Decree, the financial problems within the Department became critical, leading to the suspension of its Twelve Year Capital Improvement Program in the Fall of 1977 and the subsequent drastic reduction of personnel. The result was that the Department had no funding to meet its obligations regarding noise barriers stipulated by the Consent Decree. It was not until June of 1978 that it appeared possible that some "outside" money could be obtained to match Federal Interstate Highway funds for barrier construction. In an unprecedented action, the Pennsylvania State Legislature in October, 1978 approved $250,000 of matching funds (transfered from Revenue Sharing funding) for barrier construction. However, a requirement to award all noise barrier contracts by June 30, 1979 was also stipulated.

BARRIER ANALYSIS TECHNIQUES

As mandated by the Consent Decree, the FHWA Noise Standards' design noise levels were the basis for the determination of acceptability, with all noise receptors classified as Activity Area B (70dBA L_{10} Exterior) and Activity Area E (55 dBA L_{10} Interior) as defined by the Federal Aid Program Manual, Volume 7, Chapter 7, Section 3. (1) Application of these design noise levels and the resultant tradeoffs to provide acceptable views are discussed later.

The predicted noise levels used in the final barrier design process were generated by the FHWA Highway Traffic Noise Prediction Model. (2) When used, this model was described in draft form and was used with concurrence of the Harrisburg, Pennsylvania FHWA Division Office. This model was felt to be the most complete and acceptable technique for this particular project. Traffic data utilized in the prediction process was generated by the Delaware Valley Regional Planning Commission (DVRPC), the Metropolitan Planning Organization for the Philadelphia metropolitan area.

The FHWA Model generated exterior L_{10} noise levels for worst case noise conditions. Based on procedures outlined in the FHWA publication FHWA-TS-77-202 titled "Insulation of Buildings Against Highway Noise" (3), exterior-interior noise reduction values were calculated for typical buildings in the study area. These values, for both open and closed window, were applied in the assessment of interior noise levels and their relationship to the 55 dBA L_{10} interior design noise level. Typical calculated interior noise reduction values were 10 dBA (open window) and 27 dBA (closed window). It became readily apparent that no noise violations would be likely with closed window conditions. However, open window conditions becamme the most critical consideration for many receptors, particularly at upper story levels.

BARRIER DESIGN AND COMMUNITY PARTICIPATION IMPLICATIONS

Due to the critical time schedule imposed by the Legislature funding action and the anticipated diverse desires and opinions of the various community groups adjacent to I-95, it was determined that the barriers in the Center City Philadelphia area would be best addressed and constructed via four contract sections. These contract areas were finalized midway through the design process when logical barrier transition breaks became clear. The barrier design and community participation processes are discussed below for each contract area.

CONTRACT AREA 1 (See Figure 3)

The communities within Contract Area 1 consist mainly of 3-story residential Philadelphia row homes with some commercial activities in the form of ground floor stores and restaurants. Prior to I-95 construction, some factories and warehouses existed on the ground now occupied by I-95. In recent years, the area experienced extensive upgrading, with common row-houses being converted to mid to upper class "townhouses". With the construction of I-95 and the demolition of many multi-story factories, the view of the redeveloped Philadelphia waterfront is now an attractive attribute to the area.

In this area, adjacent residences exist from approximately 21 meters (70 feet) to 34 meters (110 feet) from the nearest edge of the I-95 travelway. Without barriers, exterior L_{10} noise levels were predicted to range from 70 to 78 dBA, with interior L_{10} open window levels ranging from 64 to 68 dBA.

In this area, I-95 transitions from an elevated roadway to an at-grade roadway (with respect to the adjacent residences). The roadway between Christian Street and Queen Street is on elevated fill with generally 2:1 slopes. I-95 crosses over Queen Street on structures and the descends towards the beginning of a cut section near Fitzwater Street.

Figure 3 indicates the location of noise barriers and noise analysis sites within this section. Except on the Queen Street structure, all barriers are constructed as precast, concrete panels between steel posts. (See Figure 4) The post' foundations are embedded from 4.9 to 5.8 meters (16 to 19 feet) to withstand a 146 kg/m^2 (30 psf) horizontal force. The community faces of the concrete panels are dyed brick red and imprinted with a brick pattern, with pointed joints using a patented process developed by the Bomanite Corporation. This type of barrier was selected after extensive community participation which included the review of numerous types of metal and masonry barrier materials. (No communities in the area were interested in wood barriers). The brick pattern was felt to fit well with the brick buildings in the area. The post and panel system generally met the desire of the Department to have certain barrier sections salvagable in the event that their movement was required when possible future ramps were opened in the area.

The post and panel barriers vary in heights from 3.0 to 4.3 meters (10 to 14 feet) and are protected by steel guardrail. In steep slope areas the support posts are anchored to poured concrete caissons (See Figure 4). The caisson diameters are 91 cm (36 inches). To facilitate drainage, prevent noise leakage gaps at the base of the barrier, and prevent erosion at the barrier base, the bottom panels are embedded from 10 to 20 cm (4 to 8 inches) in a 30 by 60 cm (1 ft. X 2 ft.) stone backfill trench.

In flat slope areas, the posts are anchored to spread footings (See Figure 4). Panel embedment is similar to that for the caisson-supported design. In flat areas a drainage swale will be constructed between the barrier and the protective guardrail.

The individual panels are 15 cm (6 in.) thick precast concrete. Panel lengths are generally 5.5 meters (18 ft.) and are in even foot width dimensions. Panels are stepped, where required in increments which enable coordination of the brick courses.

On the Queen Street structure a tan colored steel noise barrier was selected After extensive consideration by adjacent property owners, a vertically corrugated design was selected (See Figure 5). The steel barrier is generally 3 meters (10 feet) high placed on top of the existing concrete parapet. Metal support posts are welded to a steel seat plate which is secured to the existing concrete parapet by through bolting. Posts are generally 2.4 meters (8 ft.) on centers. Panels are secured to a framework attached to the posts.

All exposed steel panel surfaces are factory coated with a polyvinylfluoride film. The steel posts on the concrete panel barriers are painted with a tan colored enamel paint matching the color of the steel panels.

In the Fitzwater Street area, it was not feasible to construct a barrier of sufficient height to provide acceptable third floor noise levels. However, a barrier of approximately 4.3 meters (14 feet) was determined to be adequate to protect the first floor of adjacent residences. Such a barrier would partially obscure views of the waterfront from the second stories and was not acceptable to the community. After the Department erected temporary test panels sections of varying heights at the site, a decision was made to construct barriers in the Fitzwater Street area 3.0 meters (10 feet) high. This tradeoff is predicted to cause first floor exterior levels to exceed design noise levels by approximately 1 to 2 dBA. Exterior design noise levels at all other locations are expected to be obtained by barrier implementation.

The above described barriers are predicted to reduce exterior L_{10} noise levels by from 6 to 10 dBA. Except in the Fitzwater Street area, where no third floor attenuation is provided, 3 to 8 dBA reductions are predicted at the third story building interiors. (See Table 1, noise analysis sites 1 through 4.)

CONTRACT AREA 2 (See Figure 3)

Contract Area 2 communities are similar to Contract Area 1 communities. The residences adjacent to I-95 are approximately 36 to 55 meters (120 to 180 feet) from the I-95 travelway, and are elevated with respect to the highway. These residences are situated along the west side of Front Street and presently have a view over I-95 to the riverfront area. A cut slope descends from Front Street east to I-95.

Several alternative barrier locations were investigated in the earlier stag of study. An effective barrier location would have been along the east side of Front Street at the top of the cut section. However, this location seriously obstructed the view of the riverfront and was determined to be unacceptable. Transparent barriers at this location were investigated, but rejected mainly due to the fears of discoloration and maintenance considerations.

A barrier at or near the toe of slope became exceedingly attractive to the community when it was determined that the area behind the barrier could be backfilled to Front Street levels and utilized for parking and open space activities under a FHWA-City of Philadelphia Joint-Use Agreement. A noise barrier retaining wall was therefore designed approximately 9.1 meters (30 feet) from the I-95 travelway from Fitzwater Street to Pine Street. (See Figure 7). The adjacent community was successful in obtaining approvals for the joint-use concept and the City of Philadelphia hired a consultant to prepare designs. Department engineers, coordinating with the joint-use consultant, determined acceptable top of barrier elevations consistent with maintaining an acceptable view of the riverfront from Front Street.

This contract was let and awarded with the barrier wall and the joint-use project combined. The City of Philadelphia matched FHWA funds for the joint use items, which included sidewalks, parking areas, benches, lighting, drainage, and landscaping on top of the retained fill. The Pennsylvania Department of Transportation matched FHWA funds for the barrier wall, the retained fill, and associated drainage and utility relocation items. The barrier contract was advertised with two alternative designs - A Reinforced Earth Company wall and an Atlantic Pipe Corporation Doublewal Retaining Wall. The accepted low bid contractor opted to use the Reinforced Earth wall.

The Reinforced Earth wall is comprised of a series of interlocking panels supported by metal straps which extend back from the wall into specially prepared backfill material. The friction between the straps and the backfill material is responsible for the stability of the wall. On top of the Reinforced Earth Wall, a concrete parapet will be poured to a point 0.6 meters (2 feet) above the backfill grade. A 1.5 meter (5 feet) decorative fence will be erected on top of the parapet. The barrier wall ranges from 2.4 to 8.2 meters (8 to 27 feet) in height (from existing ground on highway side of wall to top of parapet) and extends for approximately 518 meters (1,700 feet). The barrier is protected at its highway face by a concrete Jersey barrier. Underdrain and inlets at the base of the wall are designed to provide surface and subsurface drainage. Figure 8 shows a section of the Reinforced Earth wall nearing completion. Figure 9 shows that a portion of the reclaimed area which will be developed under the joint-use agreement.

Without the barrier in this area exterior L_{10} first floor noise levels at Front Street residences are predicted to range from 72 to 74 dBA. The barrier is predicted to attenuate these levels by approximately 7 dBA. Third floor interior open window L_{10} levels are predicted to be reduced ty 3 to 6 dBA resulting in levels in the vicinity of 60 dBA. The exceeding of the 55 dBA design noise levels at the third floor is due primarily to the tradeoffs in barrier height to retain a riverfront view. (See Table 1, noise analysis sites 5 and 6.)

CONTRACT AREA 3 (See Figure 10)

The area encompassed by this contract was originally designed to be from Chestnut Street to the Benjamin Franklin Bridge. The area adjacent to I-95 along Front Street is generally commercial from Chestnut Street to Arch Street. Some residences do exist in this area. Barrier designs were developed in this area due to predicted exterior L_{10} noise levels ranging from 71 to 75 dBA. After review by the residences and businesses in this area it was determined that no barriers were desirable. This decision was based mainly on the fact that a limited easterly view presently exists and a barrier would result in total elimination of view. Also, the business community would lose its commercial "exposure" from vehicles travelling on I-95 if barriers were constructed.

From Arch Street to the Benjamin Franklin Bridge a residential community exists. This community is centered around Elfreth's Alley, the oldest inhabited street in the United States. The closest travelled lane of I-95 is approximately 15.3 meters (50 feet) from the end residence of Elfreth's Alley. The highway is constructed on retained fill with multi-level roadways. The retaining wall is faced with real brick (matching the color and type of the area's historic brick houses) and in varies in height from 3.0 to 4.9 meters (10 to 16 feet).

Noise levels without a noise barrier are predicted to be approximately 74 dBA at ground level in the Elfreth's Alley area. Third floor levels of approximately 65 dBA are expected under open window conditions. To abate these levels to the design noise levels, a barrier wall approximately 6.1 meters (20 feet) high was determined to be required. In this area, view was not a factor and the community insisted on no compromise regarding noise abatement. Therefore, the required height wall was constructed. (see Figure 11.)

Regarding aesthetic treatment, many options were discussed. The community finally insisted on a real brick faced wall between concrete columns, with the color and texture of the brick matching that of the brick on the existing retaining wall. The wall was designed as a poured reinforced concrete wall with brick facing. Because of the height of the barrier, it could not be supported structurally on the existing retaining wall. Therefore, an independent footing on the highway side of and adjacent to the existing retaining wall was designed. This required reduction of the usable existing shoulder from 3.0 meters (10 feet) to 2.4 meters (8 feet). The wall was formed in the shape of a Jersey barrier at the shoulder grade point. Figures 12 and 13 show the barrier adjacent to Elfreth's Alley nearing completion.

With the construction of the barrier, a reflection chamber was created between the new barrier and an existing retaining wall on the east side of the I-95 southbound lanes. In order to acquire the required noise attenuation of the new noise barrier, it was determined that absorptive treatment of the existing east retaining wall was necessary. Without such absorptive treatment, it was predicted, via techniques described in the FHWA Noise Barrier Design Handbook (4), that the maximum effectiveness of the new noise barrier would be degraded by about 5 to 6 dBA. The absorptive surface treatment was designed to be constructed of a perforated metal face panel with the sound absorptive filler material. A minimum sound absorption coefficient of 0.90 was specified as a requirement for the 125 Hz through 8000 Hz octave bands, with a minimum Noise Reduction Coefficient (NRC) of 0.95 required. The panels were required to have a factory applied coating similar in type and color to the metal barrier walls described in the Contract 1 area. (See Table 1, noise analysis sites 7 through 10.)

CONTRACT AREA 4 (See Figure 10)

This area is situated to the north of the Benjamin Franklin Bridge and contains residences on both sides of I-95. The community is presently undergoing change via rehabilitation of older buildings to residential dwellings. Without any barriers, exterior L_{10} noise levels were predicted to range from 74 to 76 dBA at the first floor levels. Interior L_{10} open window levels of from 64 to 66 dBA were predicted.

To provide abatement of noise levels at the third floor level equal to the 55 dBA design noise level, it was determined that barriers of up to 6.1 meters (20 feet) in height would be required. Such barriers would significantly affect view, and as such, heights were lowered to the 3.0 to 4.3 meter (10 to 14 foot) height range with the approval of the community. This tradeoff still permitted the exterior design noise levels at the first floor to be obtained (61 to 63 dBA levels with barriers) but resulted in third floor interior L_{10} open window levels exceeding the 55 dBA design noise levels by from 1 to 5 dBA.

The community in this area had an active artistic element which was interested in having the barriers express architecurally the history of the area. Upon review of many barrier material options, they expressed positive feelings regarding a concrete block wall of varying colors. Their ideas materialized into mural design multi-colored concrete block barriers. (See Figures 14 and 15). The actual designs were determined by the community and incorporated into the construction plans. The barriers are constructed of 20 x 40 x 30 cm (8 x 16 x 12 in.) nominal precast concrete blocks laid in a specific pattern. Red, blue, yellow, green, and white blocks, split faced on the community side, are utilized. Plain uncolored block was used below grade. The block wall is reinforced with concrete-filled voids and is on a continuous 0.3 x 1.8 meter (1 ft. x 6 ft.) reinforced concrete footing. For the barrier along Ramp FN, some stepping of the wall is required. Such stepping is accomplished in one block increments.

Since the blocks are colored throughout, a mirror design image appears on the highway side and is therefore visable to the motorists. The Department had initially considered stuccoing of the highway side since there was some concern regarding driver distraction. However, there appear to be varying opinions regarding this subject, with some states designing walls with design on the highway side. For this reason, it was decided that the design would be allowed to remain visible on the highway side, and an attempt made in the future to evaluate its effect on the motorists. (see Table 1, noise analysis site 11 through 13.)

BARRIER COSTS

Table 2 summarizes noise barriers costs by contract areas. Costs for the total awarded contracts plus the prices for the barriers alone are indicated. The in-place barrier costs include all items necessary to construct the barriers (material, excavation, formwork replacement of disturbed areas, and any required structure modifications) but exclude such items as maintenance of traffic, mobilization, and guardrail. The prices reflect the influence of union labor and the Philadelphia labor market. The post and panel barriers (Contract Area 1) and the reinforced concrete block barriers (Contract Area 4) both cost approximately \$237/m^2 (\$22/$ft.^2$), indicating consistency of price for free standing barriers. The price of \$363/m^2 (\$33.85/$ft.^2$) for the reinforced earth wall (Contract Area 2) included the cost of backfill material. The high price of \$912/m^2 (\$84.74/$ft.^2$) for the reinforced concrete brick faced barrier (Contract Area 3) was due to the complicated excavation (requiring sheeting), forming, shoulder removal and replacement, and brick facing operations. The majority of the \$323/m^2 (\$30/$ft.^2$) absorptive barrier cost (Contract Area 3) was due to the requirement of using steelworker and carpenter crews for erection. Structure modifications and limited quantities caused the steel barrier costs (Contract Area 1) to be higher than anticipated.

OBSERVATION OF THE DESIGN AND COMMUNITY PARTICIPATION PROCESSES

As stated previously, the determintion of the various barrier recommendations was the result of extensive community participation. The finalization of barrier locations, types, and sizes in itself was considered a major accomplishment in light of previous Department-community relationships. The agreements reached were accomplished through numerous meetings held in the area, usually in the homes of community leaders. Most meetings were at nights and were attended by 2 or 3 Department representatives and 2 or 3 community leaders. The early meetings involved informal discussions of noise models, noise theory, and noise effects. Alternative noise barrier locations were discussed extensively with major consideration given to the issue of view provided. In one area, temporary barriers were erected to aid the community in its decisions regarding barrier heights.

Many samples of barrier materials were shown to the community representatives prior to their selections. The selection of barrier materials, locations, and heights agreed to by the community leaders and the Department were presented as joint recommendations at two large public meetings. These meetings consisted of an initial two hour informal display period where individual questions were answered on a one to one basis. A short 30 to 45 minute formal joint presentation by a Department representative and a community leader followed. Slides of various alternative barrier types were included in this presentation. Following a short recess, a general question and answer period was held, followed by another one on one question and answer period. To aid in the citizens' understanding of noise levels, a audiovideo tape was taken of traffic on a local expressway. This tape was played back with a sound meter present. It's volume was adjusted to varying levels, dependent upon the desired noise level which a particular individual was interested in hearing. With the noise meter, it was possible to approximate L_{10} noise levels. The video portion also enabled the individuals to experience noise fluctuations caused by approaching and diverging traffic, both trucks and automobiles.

Each participant in the meeting was asked to complete a questionnaire indicating their feelings regarding the barrier recommendations presented, barrier material preferences, associated improvements, and noise-view tradeoffs. Results of the questionnaires were reviewed by the community leaders and Department personnel prior to formalization of the final barrier recommendations.

Regarding the design and award process, the four contracts were let in varying manners. Contract 1 was let as a performance specification. Heights and locations of barriers were given along with required transmission loss values (20dBA), surface type, gloss requirements on metal barriers, wind load, and other design restraints. Contract 2 allowed the use of either of two proprietary barrier designs. Contract 3 was let as a Department designed cast in place reinforced concrete barrier, but allowed the contractor to submit a design using reinforced concrete block as an alternative. The absorptive surface treatment in this contract was let as a performance specification. Contract 4 was let as a specific design with no alternatives allowed.

The performance specification process has the advantage of a slight savings in design time and theoretically increases competition. It places much more responsibility on the engineer during the review process and makes the writing of specifications more critical and time consuming. It also creates the possibility of not getting the exact type of method which the community and the Department desired. Usually, a barrier selection was based on the communities' review of a specific barrier manufacturer's product. Due to the inability to specify a particular product, the Department had no assurances that the low bid would contain the product which they had seen and upon which their recommendations were based. Fortunately, this problem did not materialize in Contract 1, and both the steel and concrete barrier have been provided by the suppliers whose materials were selected in the review process.

It is believed that the letting of Contract 2 with two alternative proprietary methods was an overall advantage in keeping the bid prices as reasonable as possible. On Contract 3 and 4 there were felt to be no alternative acceptable means of letting either contract.

EVALUATION OF BARRIER EFFECTIVENESS

The Departmnet intends to evaluate the effectiveness of the barriers following their completion. It was possible to monitor noise levels at several locations prior to barrier construction and after Interstate Route 95 was opened to traffic. Noise monitoring at these locations was conducted simultaneoulsy with traffic counting and speed monitoring, both of which were recorded by vehicle class and direction of flow. This speed and volume data was then input into the FHWA Highway Traffic Noise Prediction Model. The Model predicted 1 to 2 dBA higher than the actual monitored values. At analysis site 9 (See Figure 10) noise levels, traffic volumes, and traffic speeds were monitored simultaneously at ground level and upper stories with the barrier completed but without the absorptive surface treatment on the opposite wall. This monitoring was limited due to construction activity in the area. However, when the traffic volume and speed data was input into the FHWA Model, the predicted noise levels generated were several dBA lower (3dBA at elevation equivilent to top of barrier elevation and 5dBA at ground level observer elevation) than the actual monitored noise levels indicating that reflection is likely to be a significant factor in this area. Due to the limited data, any conclusive determination of actual reflective consequences must await further monitoring and analysis. The evaluation of the effectiveness of all of the noise barriers discussed herein is expected to be completed in mid-1980.

SUMMARY

In summary, Pennsylvania's first major noise barrier undertaking can be termed successful at this point in time. Through the late stages of construction, no major unsolvable problems have emerged. Much experience had been gained in both the design and citizen participation processes. The ability to advance from a stage where there was no concensus among any of the numerous affected community groups to the construction stage in a 12 month period was an undertaking thought by many to be impossible, particularly in light of previous community-Department relationships. The experience gained in this process will be invaluable in future noise barrier projects in Pennsylvania.

ACKNOWLEDGEMENTS

Completion of this noise barrier project was possible only through the dedicated efforts of the many Pennsylvania Department of Transportation and Federal Highway Administration personel involved. Special thanks go to Mr. Frank Sorrentino (design liaison engineer), Mr. Lin Chen (structural engineer), Mr. John Hanosek (Central Office review entineer), Mr. Carmine Fascina (FHWA division office review engineer), and to the members of the Department's District Contract Management, Plans, and Construction units. To Mr. Robert Rowland (District Engineer), Mr. Philip Amos (Deputy Secretary) and Mr. Robert Raymond (legal council), thanks are in order for providing the administration and legal direction necessary for the completion of this project.

REFERENCES

1. U.S. Department of Transportation, Federal Highway Administration, Federal-Aid Highway Program Manual, Volume 7, Chapter 7, Section 3; Washington, D.C. May, 1976.

2. U.S. Department of Transportation, Federal Highway Administration; FHWA Highway Traffic Noise Prediction Model, Draft, Washington, D.C.: December 1977.

3. Davy Bruce A. and Skale, Steven R.; Insulation of Buildings Against Highway Noise, FHWA Report TS-77-202; Washington, D.C.; 1977.

4. Simpson, Miles A.; Noise Barrier Design Handbook, FHWA Report RD-76-58; Washington, D.C.; February, 1976.

LIST OF TABLES

TABLE 1

NOISE DATA SUMMARY

NOISE ANALYSIS SITE *	L_{10} NOISE LEVELS				
	EXTERIOR 1st FLOOR PRIOR TO CONSTRUCTION OF I-95	WITHOUT BARRIERS		WITH BARRIERS	
		1st FLOOR EXTERIOR	3rd FLOOR INTERIOR-OPEN WINDOWS	1st FLOOR EXTERIOR	3rd FLOOR INTERIOR-OPEN WINDOWS
1	68	71	65	62	57
2	68	70	64	62	56
3	61	78	68	68	67
4	61	78	68	71	68
5	69	74	64	67	61
6	71	72	66	64	60
7	75	71	66	Barrier Not Recommended	
8	71	75	68	Barrier Not Recommended	
9	71	74	65	60	55
10	N.A.	N.C.	58	N.C.	51
11	79	75	65	62	61
12	79	76	66	61	55
13	N.A.	74	64	63	58

* For location of noise analysis sites see Figure 3 and 7; all sites are residences

N.A. = Monitored data not available

N.C. = Value not calculated

TABLE 2

SUMMARY OF NOISE BARRIER COSTS

CONTRACT AREA	TOTAL CONTRACT AWARD COST	BARRIER AREA	INPLACE BARRIER COST	INPLACE BARRIER COST/AREA
1	$773,783	271 m^2 (2,913 $ft.^2$) (Steel) 1,563 m^2 (16,828 $ft.^2$) (Post & Panel)	$105,967 $370,216	$391/$m^2$ ($36.37/$ft.^2$) $237/$m^2$ ($22.00/$ft.^2$)
2	$2,341,022	3,533 m^2 (38,035 $ft.^2$)	$1,287,381	$364/$m^2$ ($33.85/$ft.^2$)
3	$1,305,363	1,214 m^2 (13,073 $ft.^2$) (Brick faced Concrete) 181 m^2 (1,953 $ft.^2$) (Absorptive Treatment)	$1,107,786 $58,590	$912/$m^2$ ($84.74/$ft.^2$) $323/$m^2$ ($30.00/$ft.^2$)
4	$793,365	2,590 m^2 (27,882 $ft.^2$)	$623,828	$241/$m^2$ ($22.37/$ft.^2$)

LIST OF FIGURES

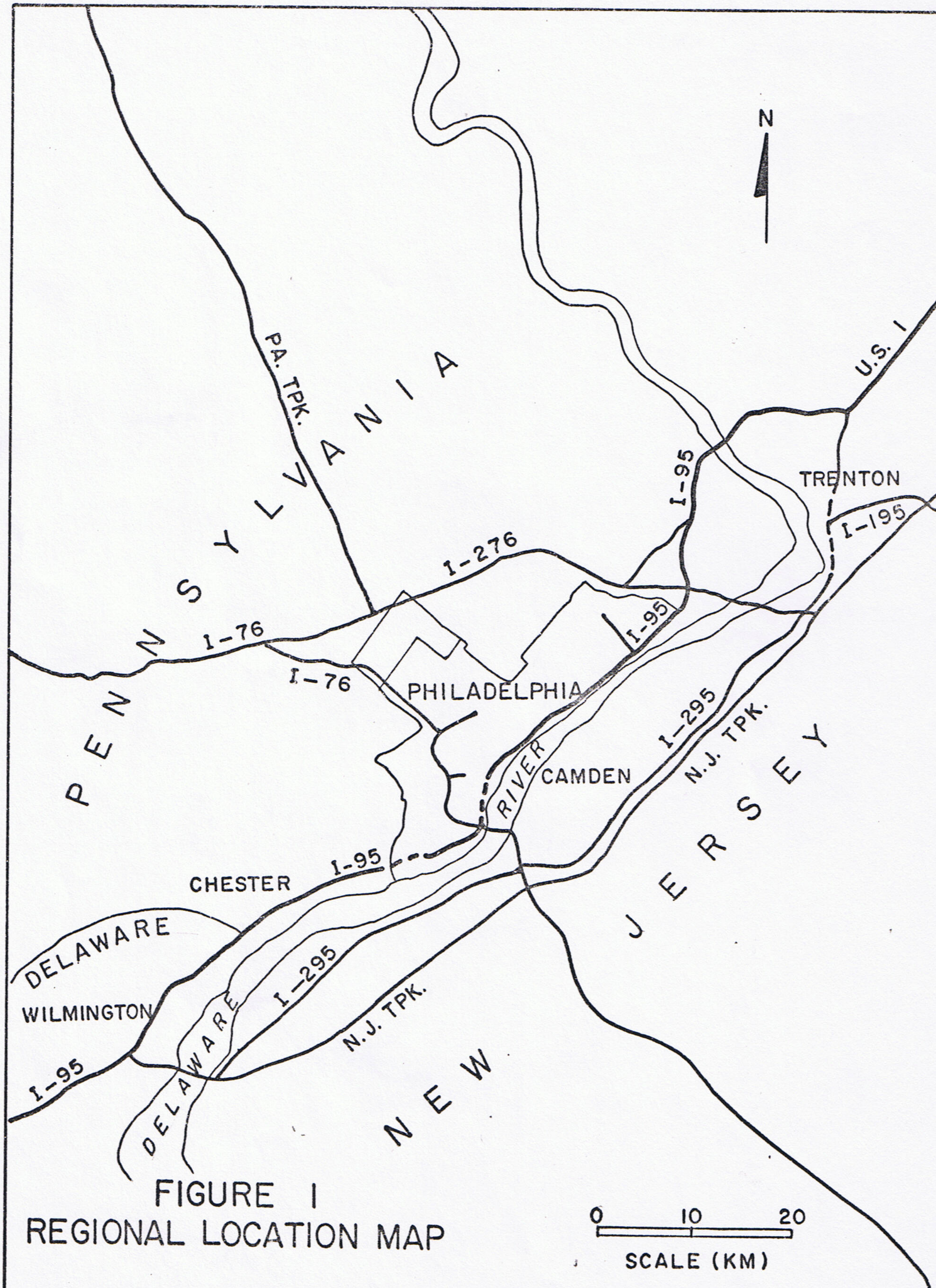


FIGURE I
REGIONAL LOCATION MAP

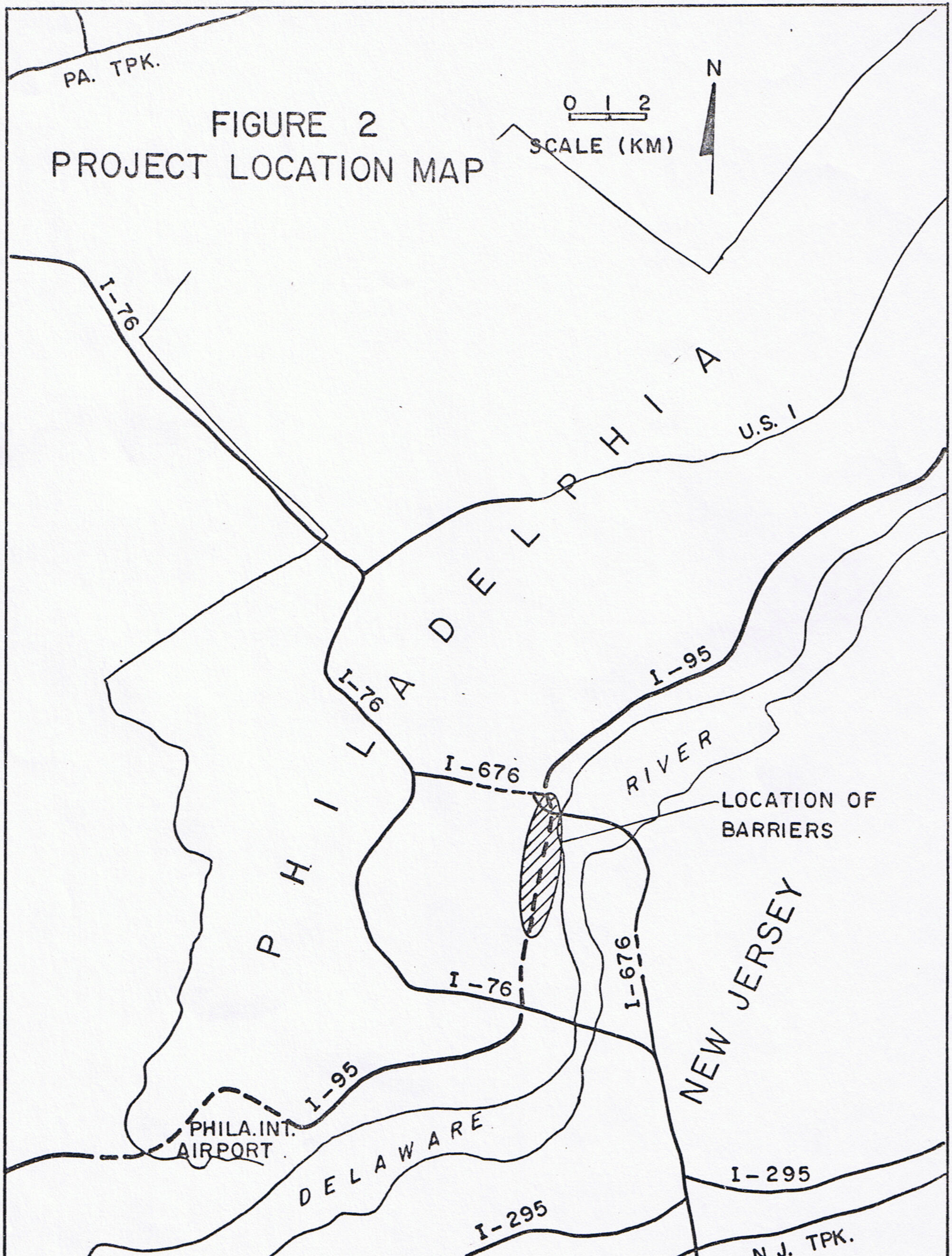


FIGURE 2
PROJECT LOCATION MAP
PA. TPK.
0 1 2
SCALE (KM)
N
I-76
PHILADELPHIA
U.S. 1
I-95
I-76
I-676
RIVER
LOCATION OF BARRIERS
NEW JERSEY
I-676
I-76
I-95
PHILA.INT. AIRPORT
DELAWARE
I-295
I-295
N.J. TPK.

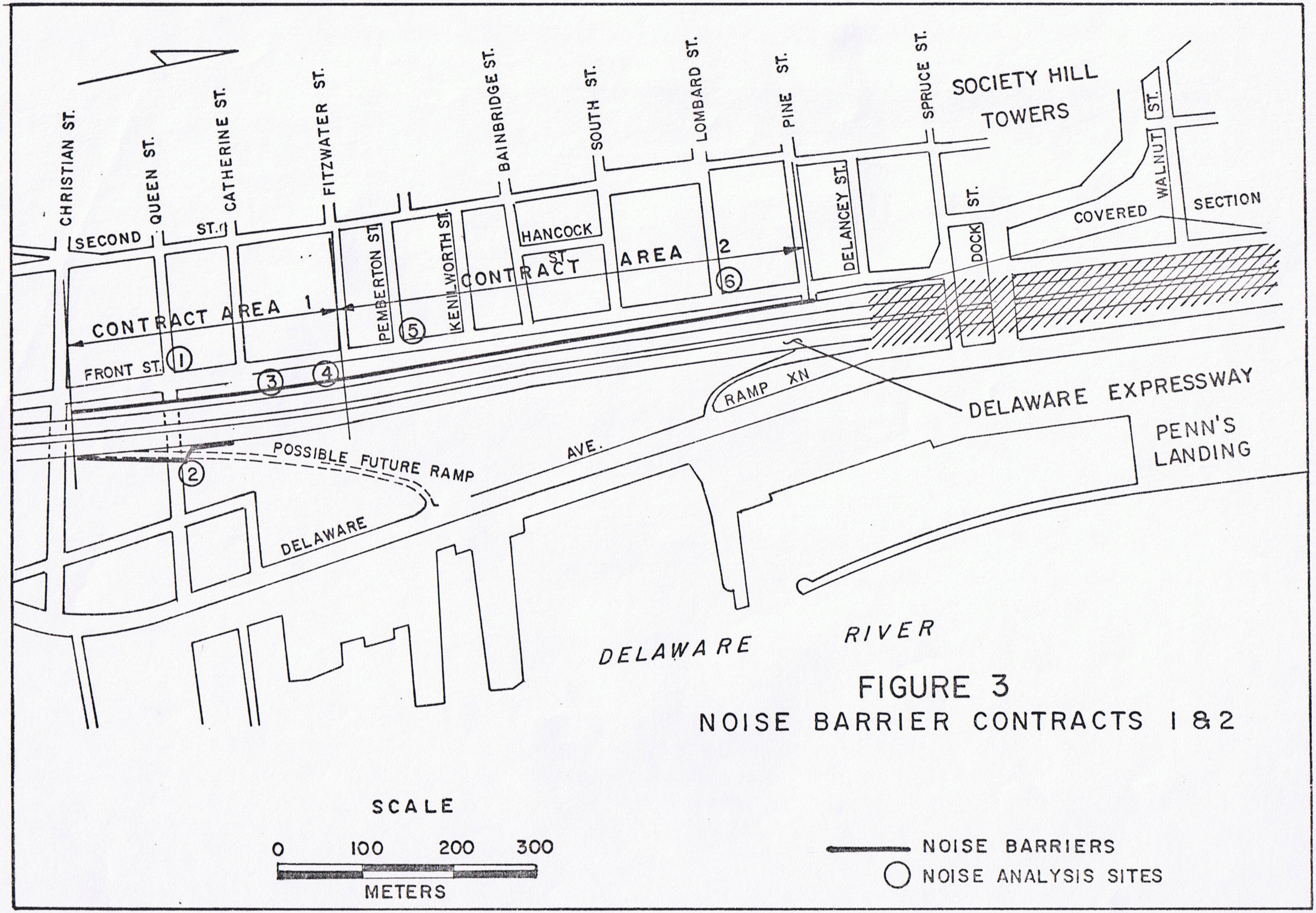


FIGURE 3
NOISE BARRIER CONTRACTS 1 & 2

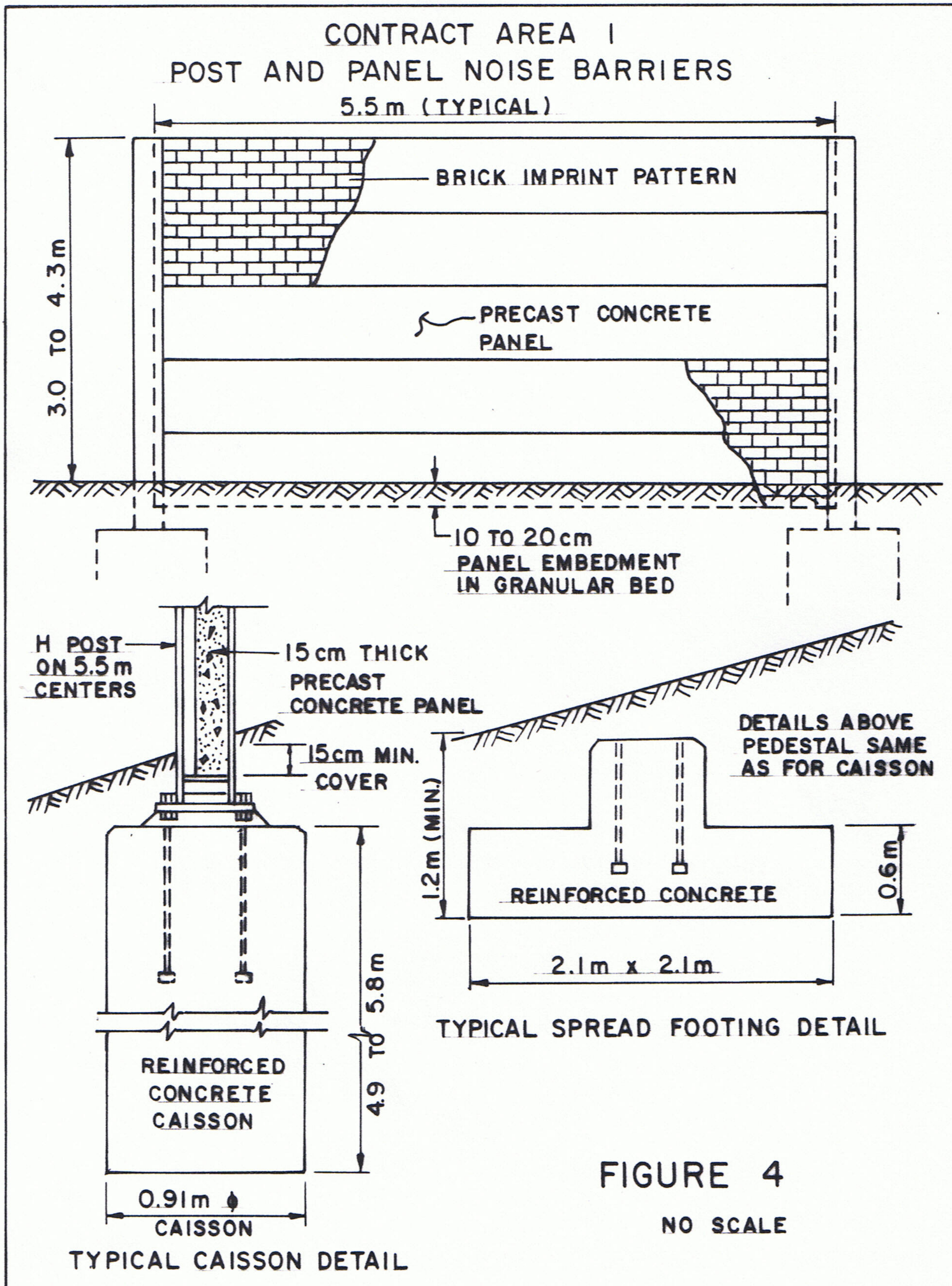
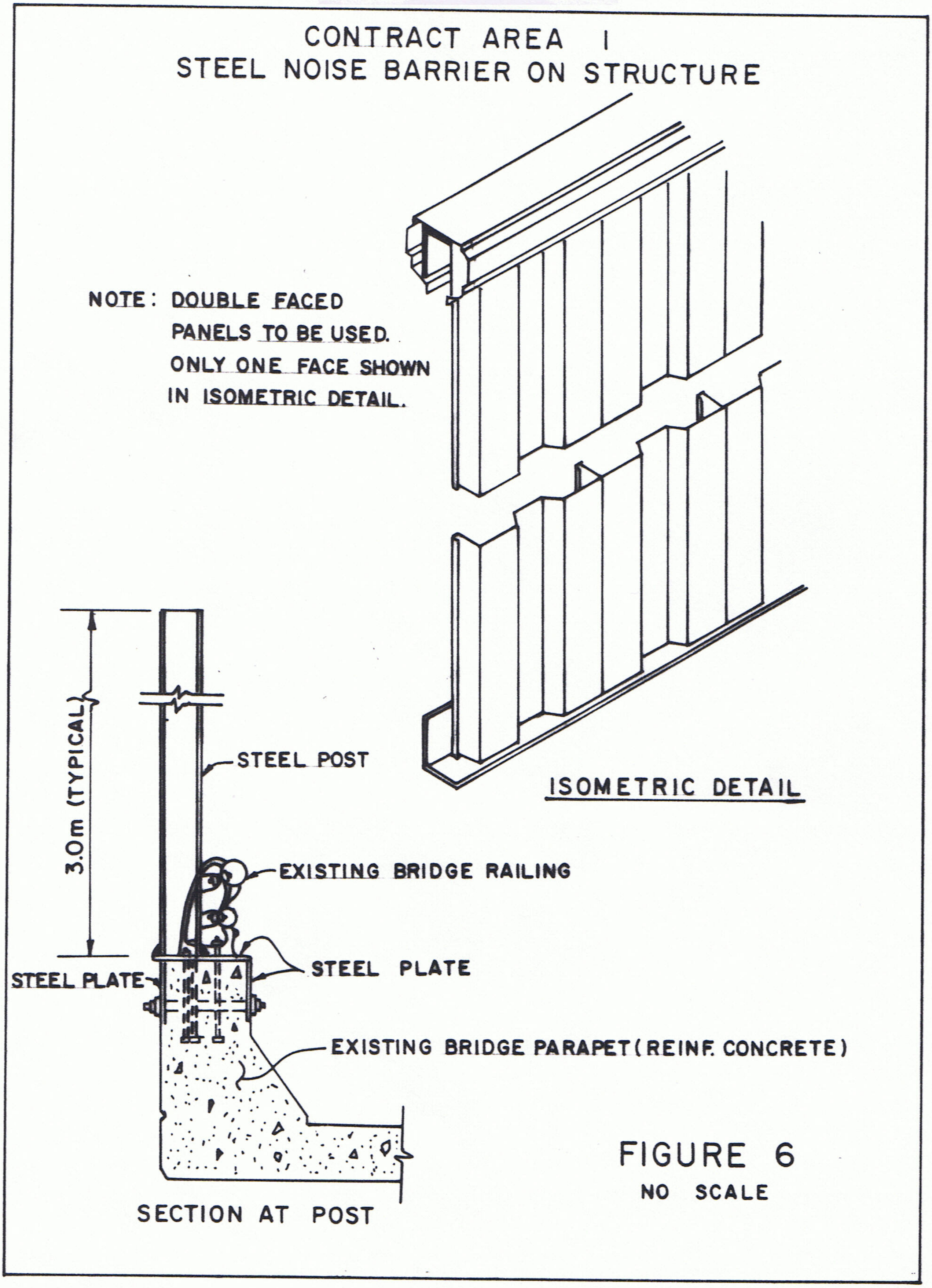


FIGURE 4

NO SCALE


CONTRACT AREA I
STEEL NOISE BARRIER ON STRUCTURE
NOTE: DOUBLE FACED PANELS TO BE USED. ONLY ONE FACE SHOWN IN ISOMETRIC DETAIL.
ISOMETRIC DETAIL
3.0m (TYPICAL)
STEEL POST
EXISTING BRIDGE RAILING
STEEL PLATE
STEEL PLATE
EXISTING BRIDGE PARAPET (REINF. CONCRETE)
SECTION AT POST
FIGURE 6
NO SCALE

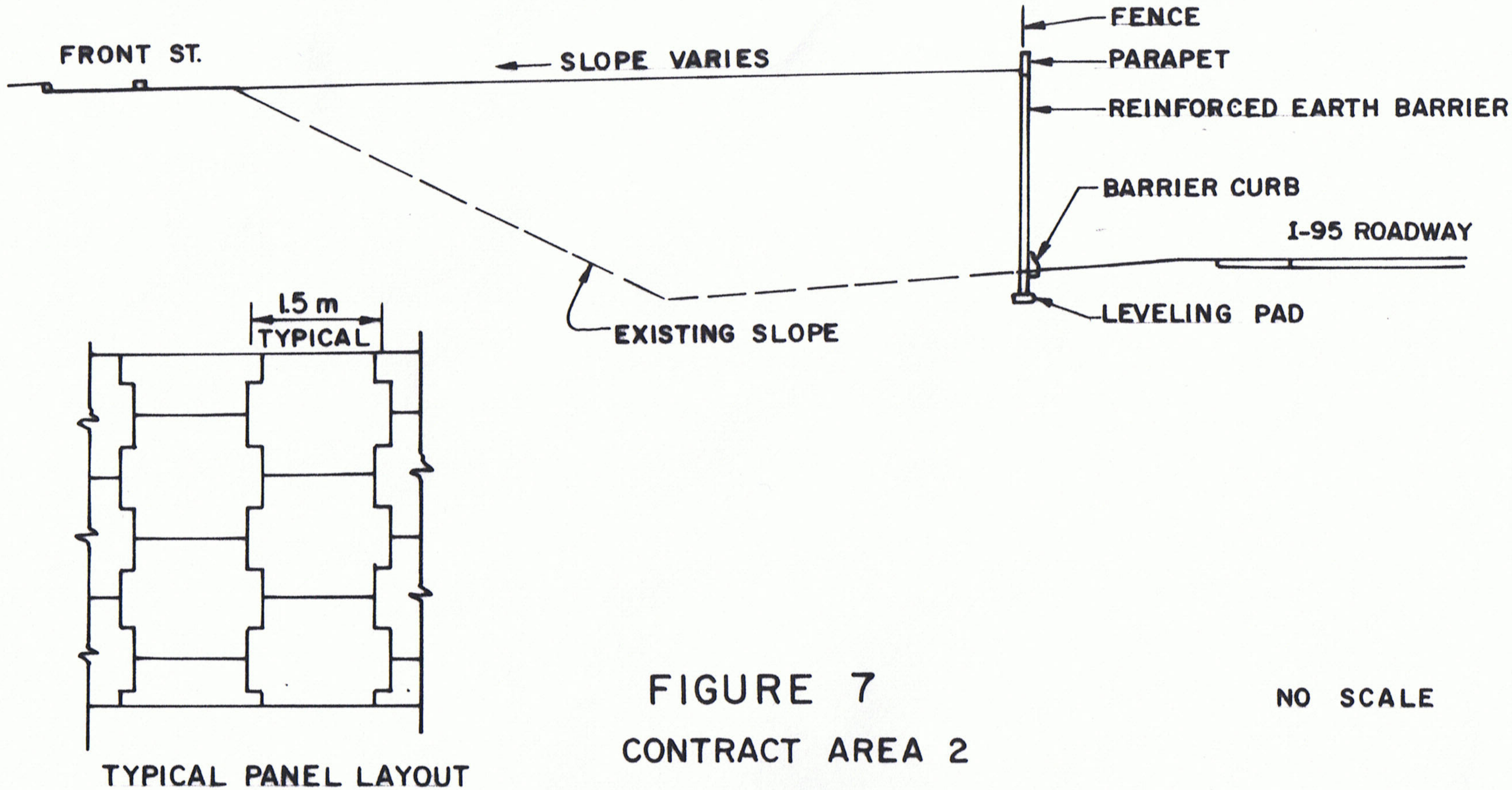


FIGURE 7

CONTRACT AREA 2

REINFORCED EARTH NOISE BARRIER

FIGURE 8 - REINFORCED EARTH WALL (UNDER CONSTRUCTION)

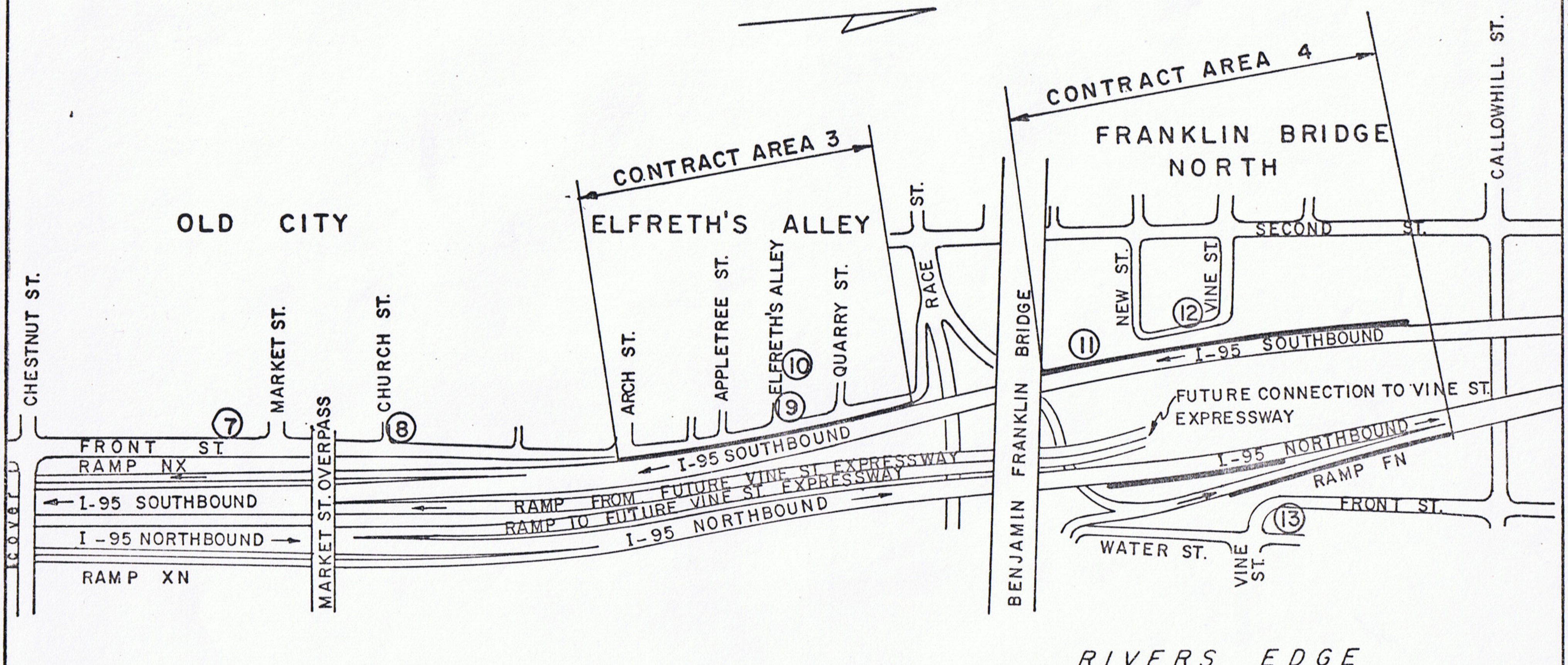


FIGURE 10

NOISE BARRIER CONTRACTS 3 & 4

0 50 100

SCALE IN METERS

NOISE BARRIERS

NOISE ANALYSIS SITE

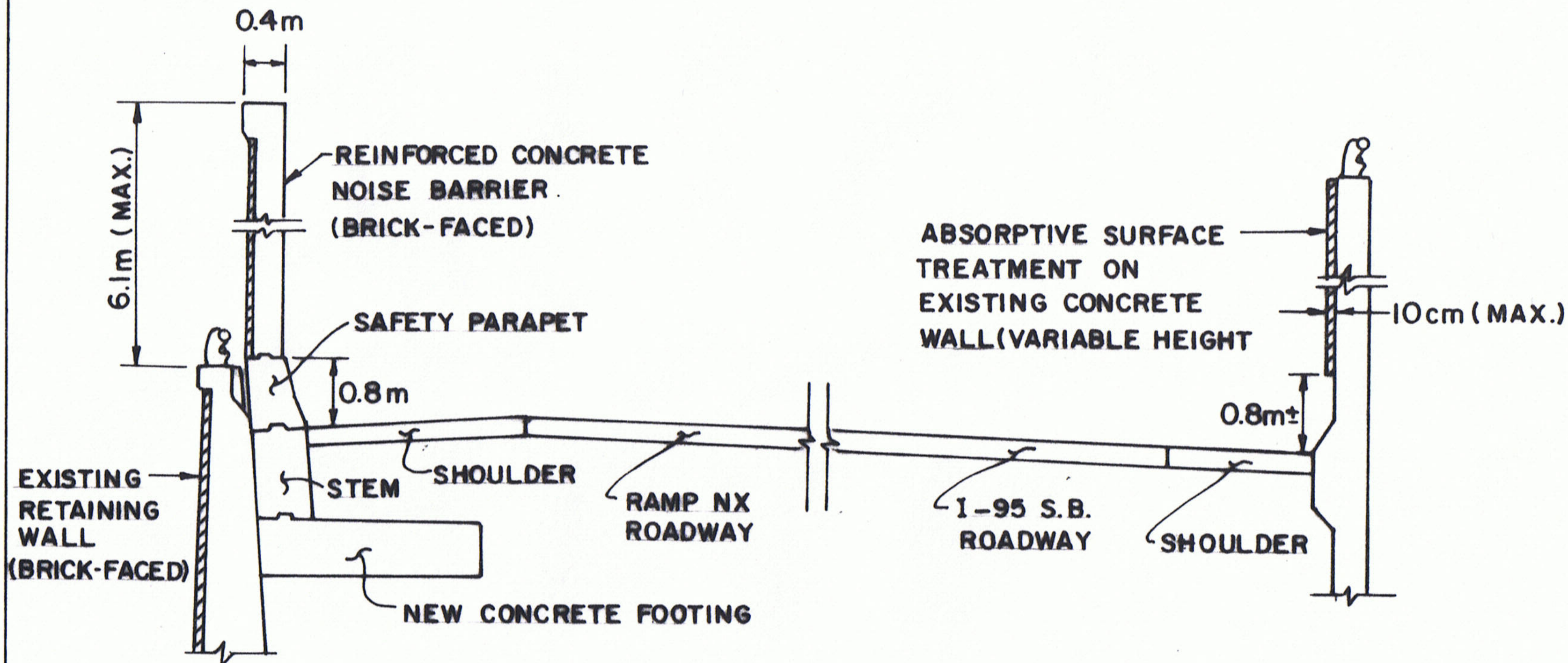


FIGURE 11

CONTRACT AREA 3

REINFORCED CONCRETE NOISE BARRIER AND ABSORPTIVE SURFACE TREATMENT

NO SCALE

Harvey S. Knauer

CONTRACT AREA 4

REINFORCED MULTI-COLORED CONCRETE BLOCK BARRIER

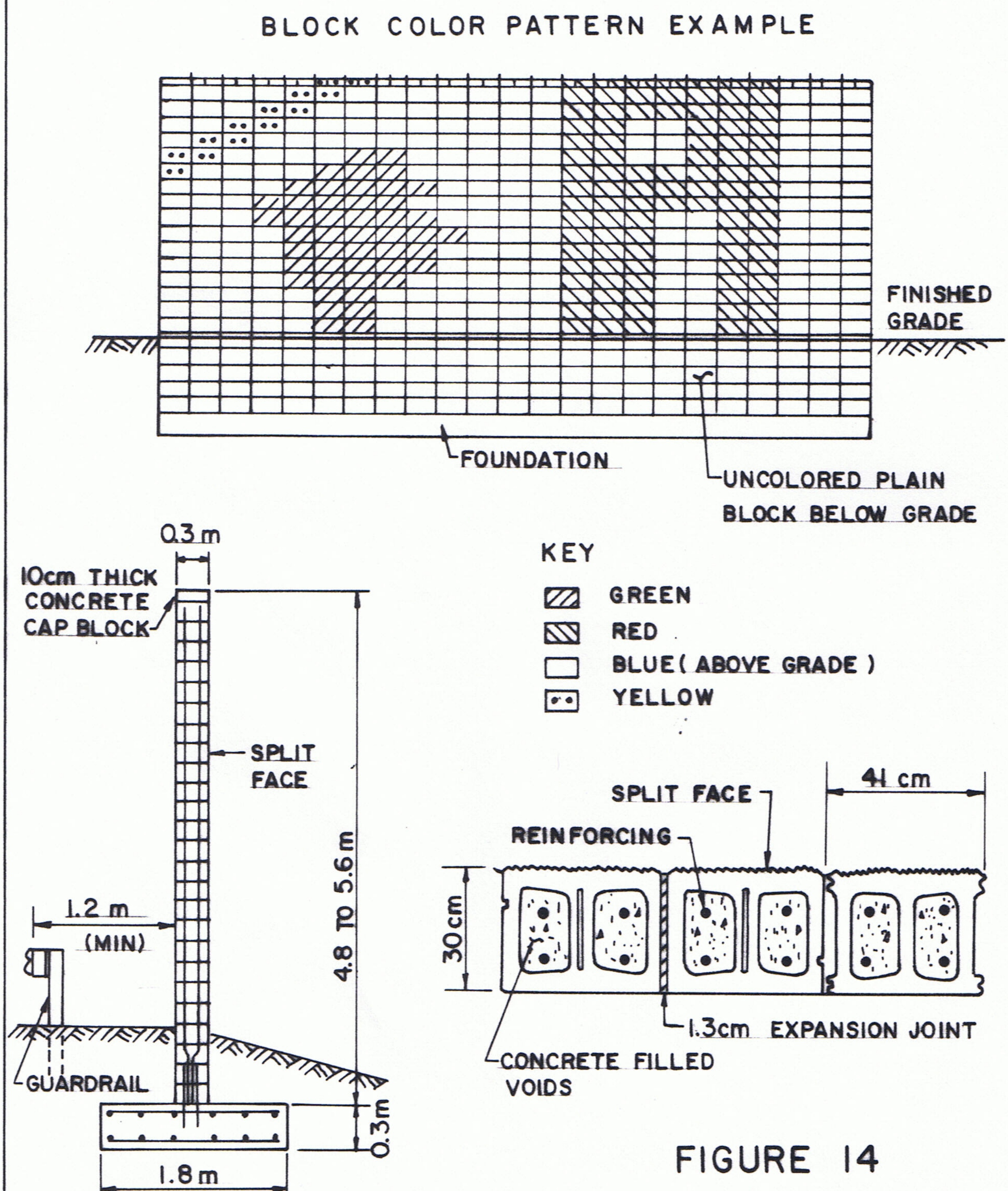


FIGURE 14

NO SCALE

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