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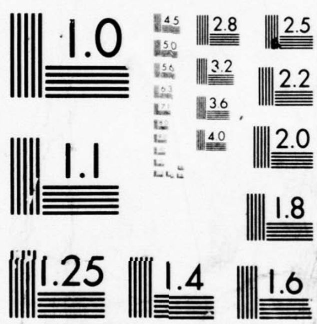

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TECHNICAL REPORT

INTEGRATION OF FIRE PROTECTION INTO LARGE AUTOMATED STORAGE SYSTEMS AT NAVAL SHORE FACILITIES PHASE II

By:
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and
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ABSTRACT

Two methods of integrating automatic sprinkler protection into high rise, rack storage systems are described with the aid of detailed sketches. The two schemes are hydraulically analyzed and compared to the performance of conventional systems. A cost effectiveness analysis is made of one system which utilizes tubular rack columns as water conductors.

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INTRODUCTION

1.1 BACKGROUND

Whenever large quantities of combustible materials are gathered together, a fire hazard is created; but the degree of hazard depends on the type and geometric arrangement of the materials. If the combustibles are placed in high storage racks, the hazard is severe. In fact, it would be difficult to devise a more efficient way to pile combustibles for burning. Rack storage systems contain vertical flue spaces and horizontal channels that permit a free circulation of air. In case of ignition, the upward spread of fire is rapid because of the chimney effect created by the vertical flue spaces. At the same time, pressure differences force the fire through the horizontal channels and the flames spread quickly in all directions. If the fire is left unchecked, the entire storage system may soon be in flames.

Traditionally, warehouses have been protected from fire by the installation of automatic sprinklers at the ceiling. However, the discharge from ceiling sprinklers cannot readily reach the lower tiers of a storage rack and when pile heights exceed 25 ft, ceiling sprinklers lose effectiveness (in some cases, the loss in effectiveness occurs well below 25 ft). In order for automatic sprinklers to be effective, the ceiling sprinklers must be supplemented by intermediate levels of sprinklers installed at strategic locations in the rack.

Usually, the storage system is designed and fabricated without making allowance for the installation of sprinklers. The in-rack sprinklers must then be fitted into the rack structure as best they can. As a result, the installation of in-rack sprinklers is often difficult and expensive. They may encroach upon storage space and cause interference with automated materials handling equipment. Further, the extinguishing potential of the sprinkler system may also suffer due to the uncoordinated design.

Integrating sprinkler protection into the basic design of large, automated storage systems will optimize both effectiveness and cost.

This project is a continuation of the work started under NavFac Contract N00025-73-C-0032. The previous work is covered in a report issued under FMRC Serial No. 21289, dated August 1974. In that report, the history and development of rack storage fire protection was reviewed and the state of the art surveyed. Constraints imposed on fire protection by the construction and operational requirements of high rack storage systems were outlined and two methods of integrating sprinkler protection into rack storage systems were suggested.

1.2 OBJECTIVE

The objective of this project is the development of an integrated sprinkler system for the fire protection of future Navy high rise storage systems such as those intended for the TRIDENT and NATIONAL CITY, CA. installations. Specifically, the objective will be reached as follows:

1. The two methods of integration suggested in the Phase I report will be revised and developed to the extent necessary for practical implementation.
2. The two systems developed under 1 above will be hydraulically analyzed.
3. A cost-effectiveness analysis will bmade and compared to the cost of conventional methods of sprinkler protection.

NOTE:

The placement of sprinklers within the rack structure will follow proven arrangements as called for by NFPA Standard 231C. These arrangements have been developed from many large scale fire tests, as explained in the Phase I report. In view of this fact, it is believed that additional fire testing is unnecessary. It is also anticipated that the hydraulic performance of the integrated sprinkler systems will be adequately determined from the analyses conducted under item 2 above and that water flow tests will, therefore, be unnecessary. However, small scale testing will be conducted if unforeseen difficulties arise which make testing advisable.

II

LARGE STORAGE FACILITIES WITH HIGH RISE STORAGE RACKS

2.1 EXAMPLE OF A LARGE STORAGE FACILITY

A warehouse may be of almost any size or shape and the storage system may assume a variety of configurations. It is, therefore, impossible to define a "typical" warehouse. Nevertheless; it is helpful, in fixing ideas, to select a specific example as a reference. With this in mind, the storage facility shown in Figures 1 and 2 may be considered to be of a type and size that is of interest in this study.

The high rise storage racks are double row, open steel frame construction with transverse pallet supports. Stacking machinery is of the mobile elevator type and is computer-controlled to deliver and retrieve pallet loads to and from storage. In this particular example, a low bay section of the building contains 20-ft high storage racks that are loaded and unloaded with fork lift trucks; but some facilities may be devoted entirely to high rise storage. In any case, the facility illustrated in Figures 1 and 2 will serve as a model for this project.

2.2 TYPE OF PROTECTION TO BE CONSIDERED

Several methods of protection are described in the Phase I report, but only automatic sprinklers have been proven effective and economical for all storage heights. Since it is desirable to standardize protection without regard for storage height, automatic sprinklers offer the only economical means of achieving the required flexibility. Automatic sprinklers have other desirable qualities (see the Phase I report) that make them an excellent choice for the protection of high rack storages. Therefore, only automatic sprinklers are considered for this application.

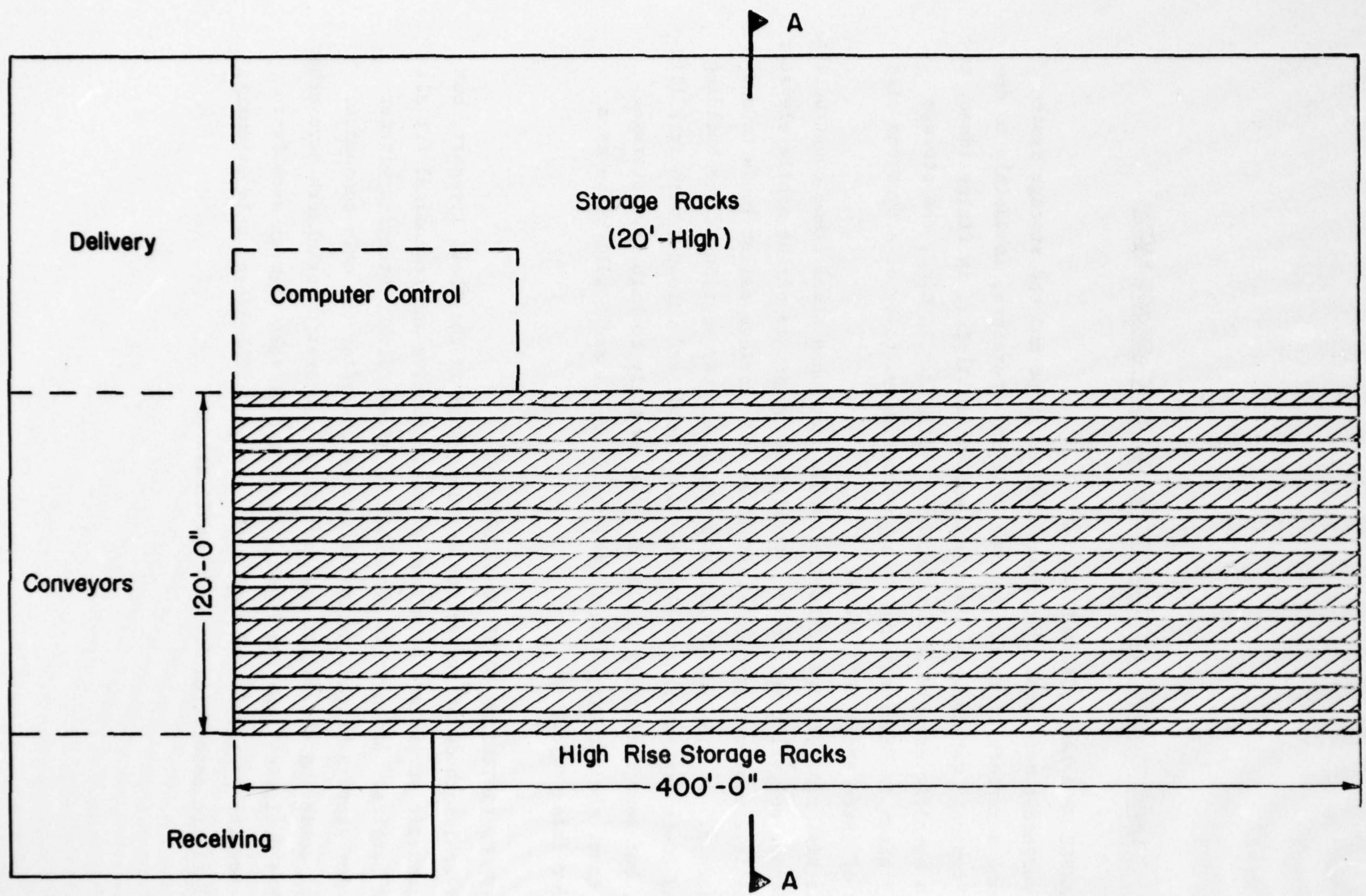


Figure No. 1. Example of Large Storage Facility, Plan View

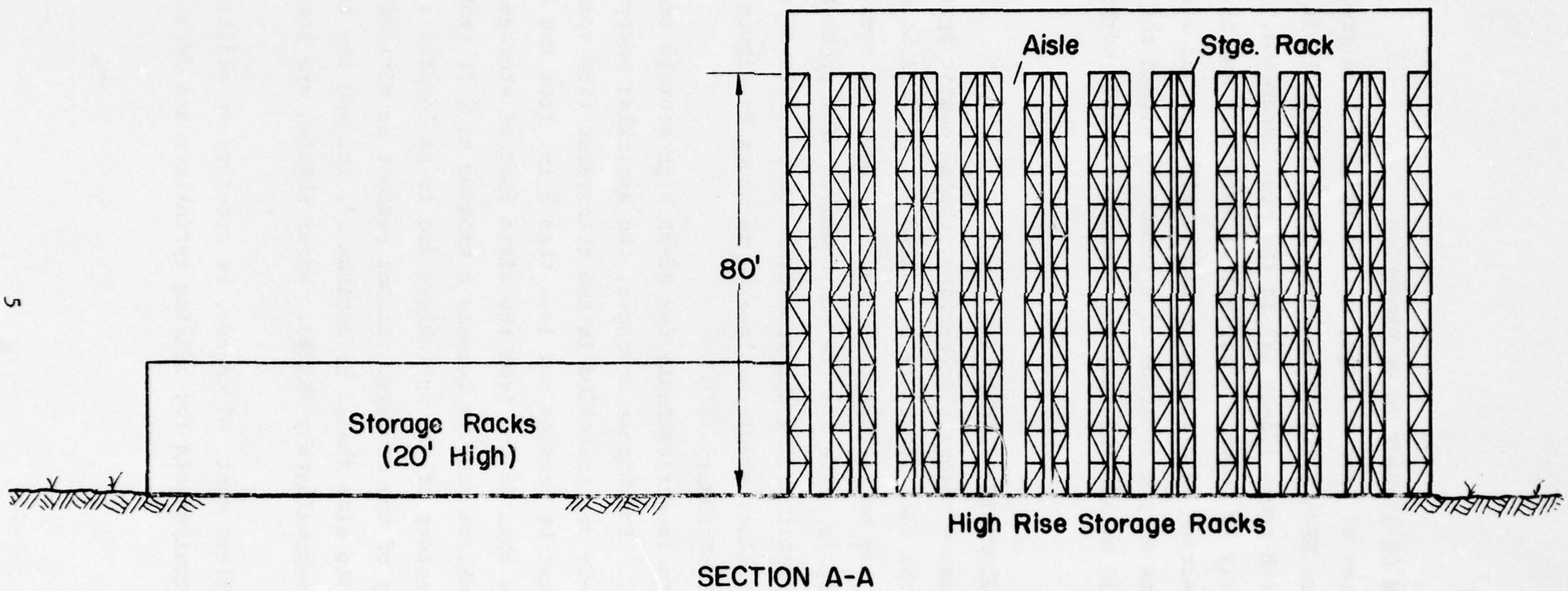


Figure No. 2. Example of Large Storage Facility, Sectional View

2.3 CLASSIFICATION OF STORAGE TO BE PROTECTED

For the purposes of rack storage, materials have been grouped into four classifications (see NFPA 231C). The first group (Class I) is the least hazardous and the fourth group (Class IV) is the most hazardous. Naval storage facilities are likely to contain a variety of materials and it is desirable that the fire protection be arranged to handle all types of storage without placing restrictions on the location of a commodity within the rack structure. Therefore, it should be assumed that all commodities fall within the Class IV designation.

2.4 LOCATION OF AUTOMATIC SPRINKLERS

In order to assure adequate protection, the automatic sprinklers should be located within the rack structure as called for by NFPA Standard 231C. Other arrangements may be satisfactory, but they have not been proven by comprehensive, large scale tests and the consequences of a protection failure are too severe to permit basing the protection on conjectural schemes. Accordingly, the sprinklers should be located as shown by Figure 4152h or Figure 4152i in NFPA Standard 231C.

The two acceptable arrangements for 80-ft high storage are illustrated in Figures 3 and 11. For higher storages, the sprinkler pattern is repeated. The "face" sprinklers are installed in the transverse flue spaces behind the rack columns and must be located not less than 3 in. from the back of the column and not more than 18 in. from the aisle face of storage. The "longitudinal" flue sprinklers must be located a minimum of 2 ft from the rack columns. The deflectors of all sprinklers are to be located a minimum of 6 in. above the top of the storage. Either pendent or upright sprinklers may be used. The orifice size should be nominal 1/2 in. and the temperature rating must be ordinary (approximately 165°F). Water shields are installed above each sprinkler.

Ceiling sprinklers must, of course, be provided in addition to the in-rack sprinklers. The requirements for ceiling sprinklers are detailed in NFPA 231C.

2.5 INTEGRATING IN-RACK SPRINKLERS WITH A HIGH RISE STORAGE SYSTEM BY UTILIZING TUBULAR RACK COLUMNS AS WATER CONDUCTORS

A high rise storage rack may be constructed with tubular columns of square or rectangular cross section. The columns may be sealed and used as pipes to conduct water to automatic sprinklers placed at various points within the rack structure. The sprinklers should be located in accordance with NFPA Standard 231C. An acceptable arrangement of sprinklers for a double row rack structure is shown in Figure 3 (note that the sprinklers are staggered both vertically and horizontally). The sprinklers are connected to the tubular columns by short lengths of pipe and the columns are connected to a water supply through feed pipes connected to the tops of the columns. A pictorial sketch of the arrangement is shown in Figure 4 (for clarity, one of the double rows has been omitted).

The approximate vertical locations for the sprinklers are indicated in Figures 3 and 4. However, the exact locations will vary somewhat depending on the tier height. The sprinkler deflectors should be located at least 6 in. above the top of the storage in each tier (see Figure 9).

A partial plan view of the sprinkler system is shown in Figure 5. The important thing to notice is that only three rows of columns are fed with water. Sprinklers need not be attached to the fourth row. Figure 6 shows an end view and a partial elevation.

Details of column fabrication are indicated in Figures 7 and 8. Steel plates are welded to the top and bottom of the columns. A 2 1/2-in. hole is drilled in the top plate and a 2 1/2-in. half coupling welded in place. The top coupling serves as the means of attaching the feed pipe to the column. One-inch holes are drilled in the sides of the columns and 1-in. half couplings welded in place over the holes. The 1-in. couplings are for attachment of the sprinkler assemblies (see Figures 9 and 10). The plates and couplings are attached to the columns during shop fabrication.

Figures 9 and 10 show the details of the sprinkler assemblies and are self-explanatory. The sprinkler assemblies are attached to the rack columns after the rack structure has been erected at the building site.

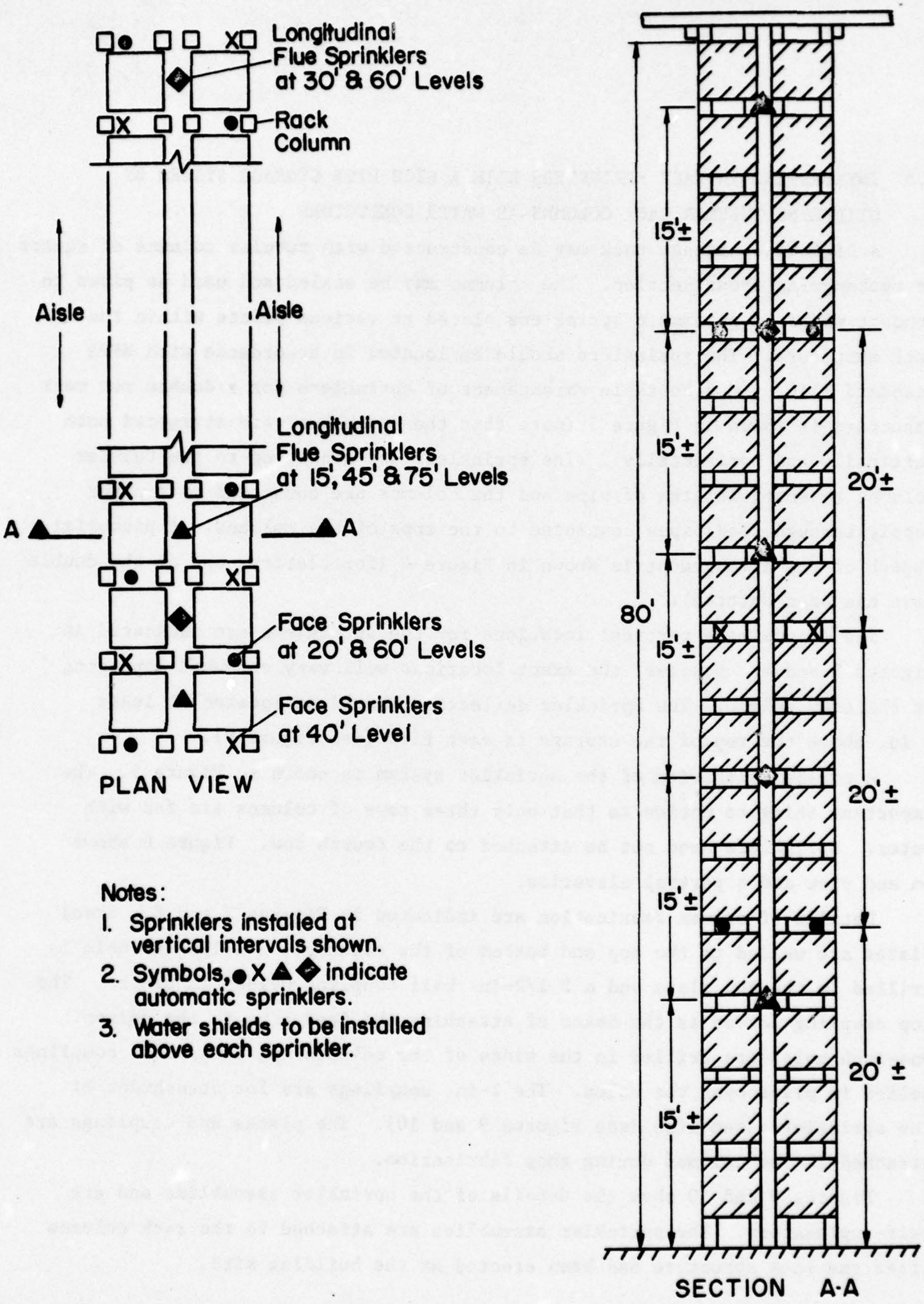


Figure No. 3. Location of In-Rack Sprinklers for Integrated System Utilizing Tubular Rack Columns as Water Conductors.

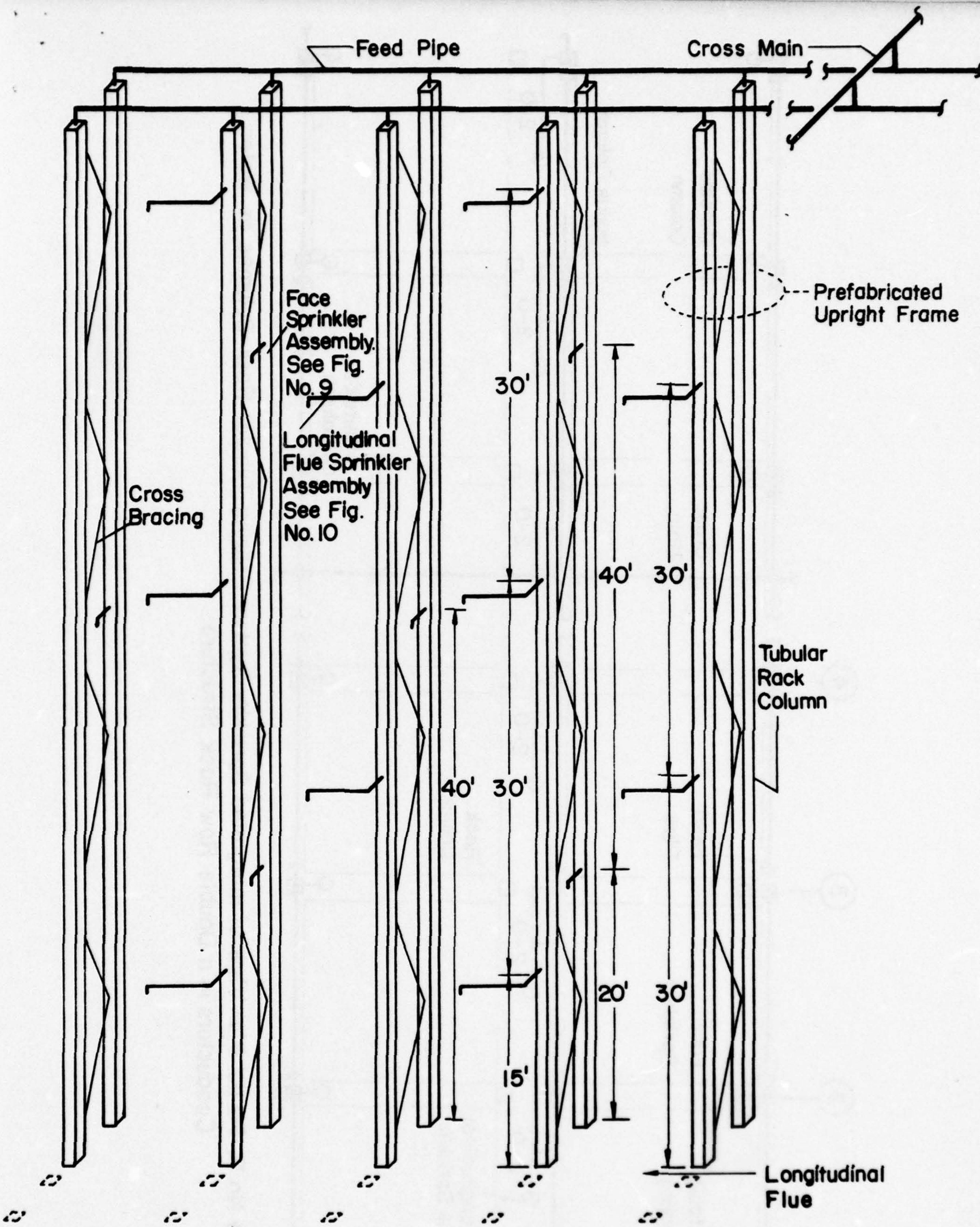


Figure No. 4. Pictorial Sketch of Integrated Sprinkler System Utilizing Tubular Rack Columns as Water Conductors.

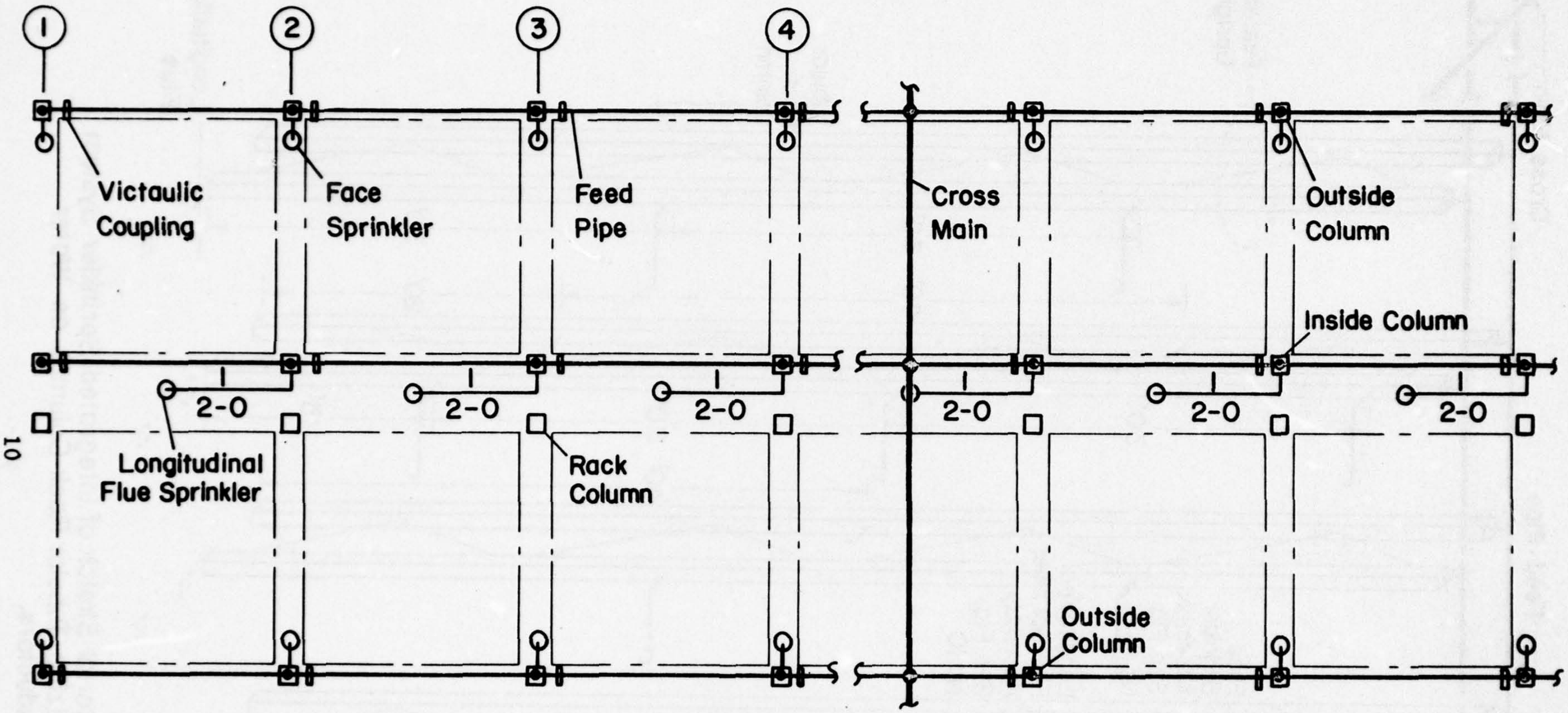


Figure No. 5. Partial Plan View of Integrated Sprinkler System Utilizing Tubular Rack Columns as Water Conductors in a Double Row Rack Structure.

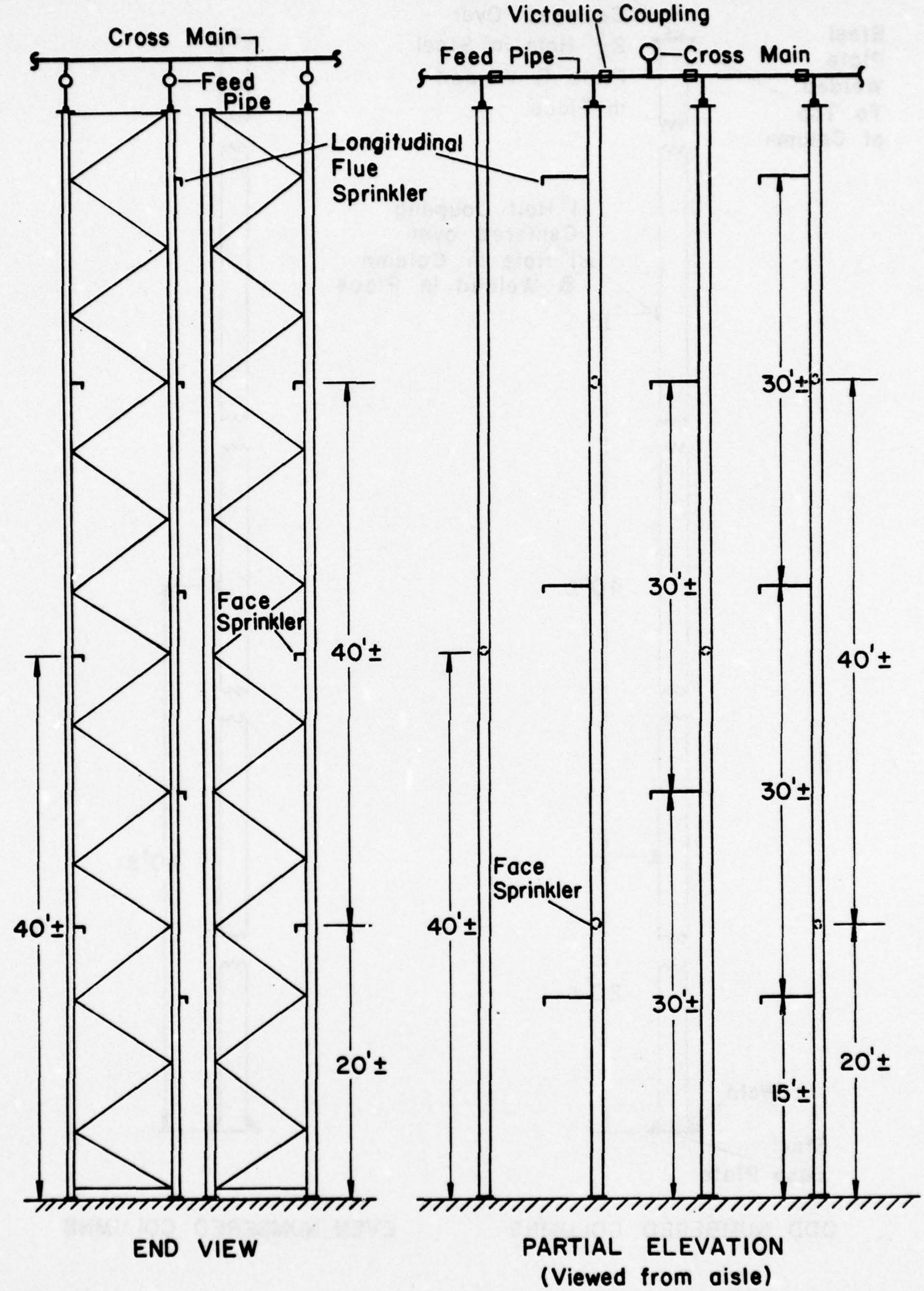

Cross Main
Feed Pipe
Longitudinal Flue Sprinkler
Face Sprinkler
40'±
40'±
20'±
END VIEW
Victaulic Coupling
Feed Pipe
Cross Main
Face Sprinkler
40'±
30'±
30'±
30'±
30'±
15'±
40'±
20'±
PARTIAL ELEVATION
(Viewed from aisle)

Figure. No. 6

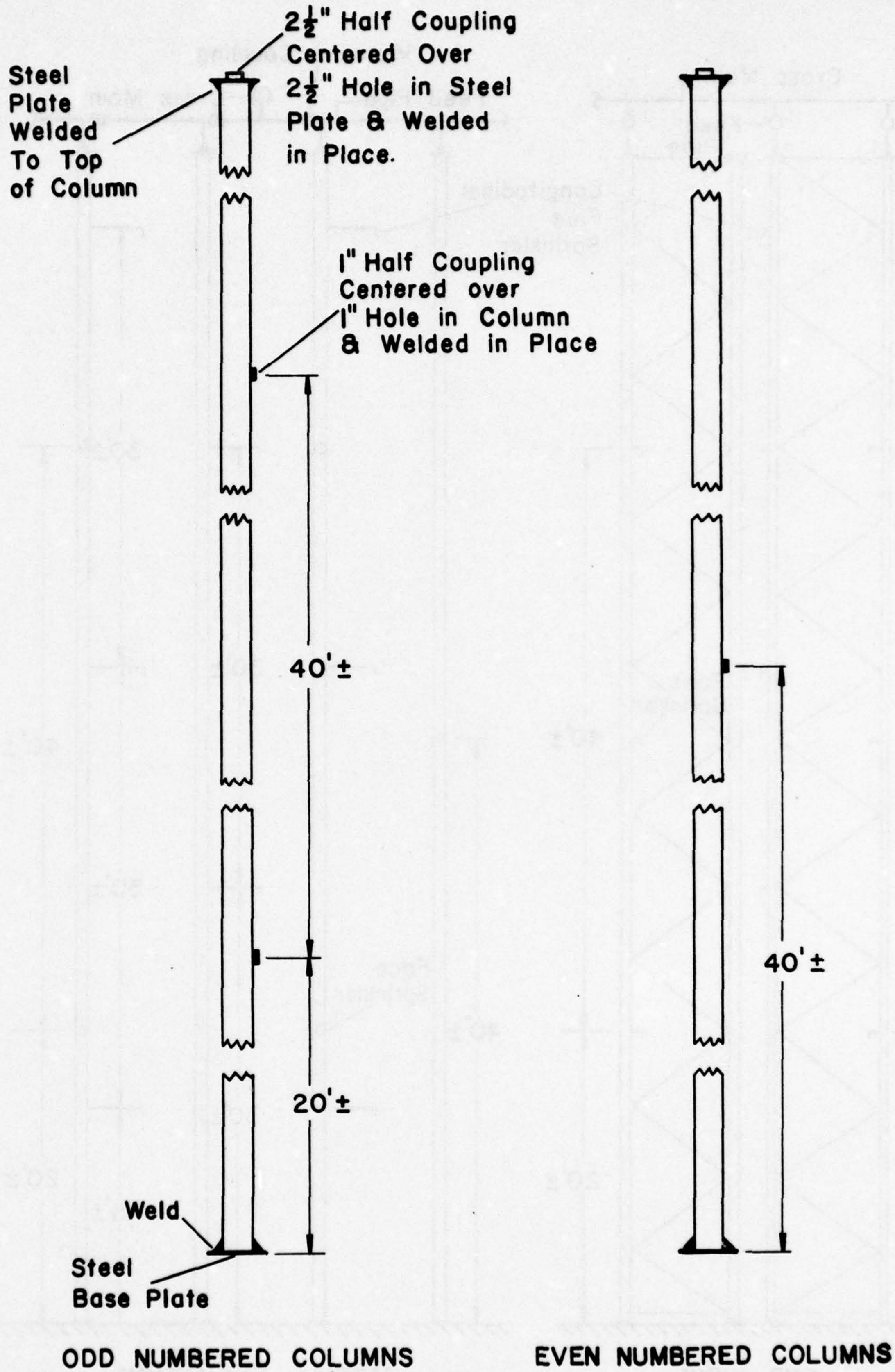


Figure. No. 7. Fabrication of Outside Tubular Rack Columns to be used as Water Conductors.

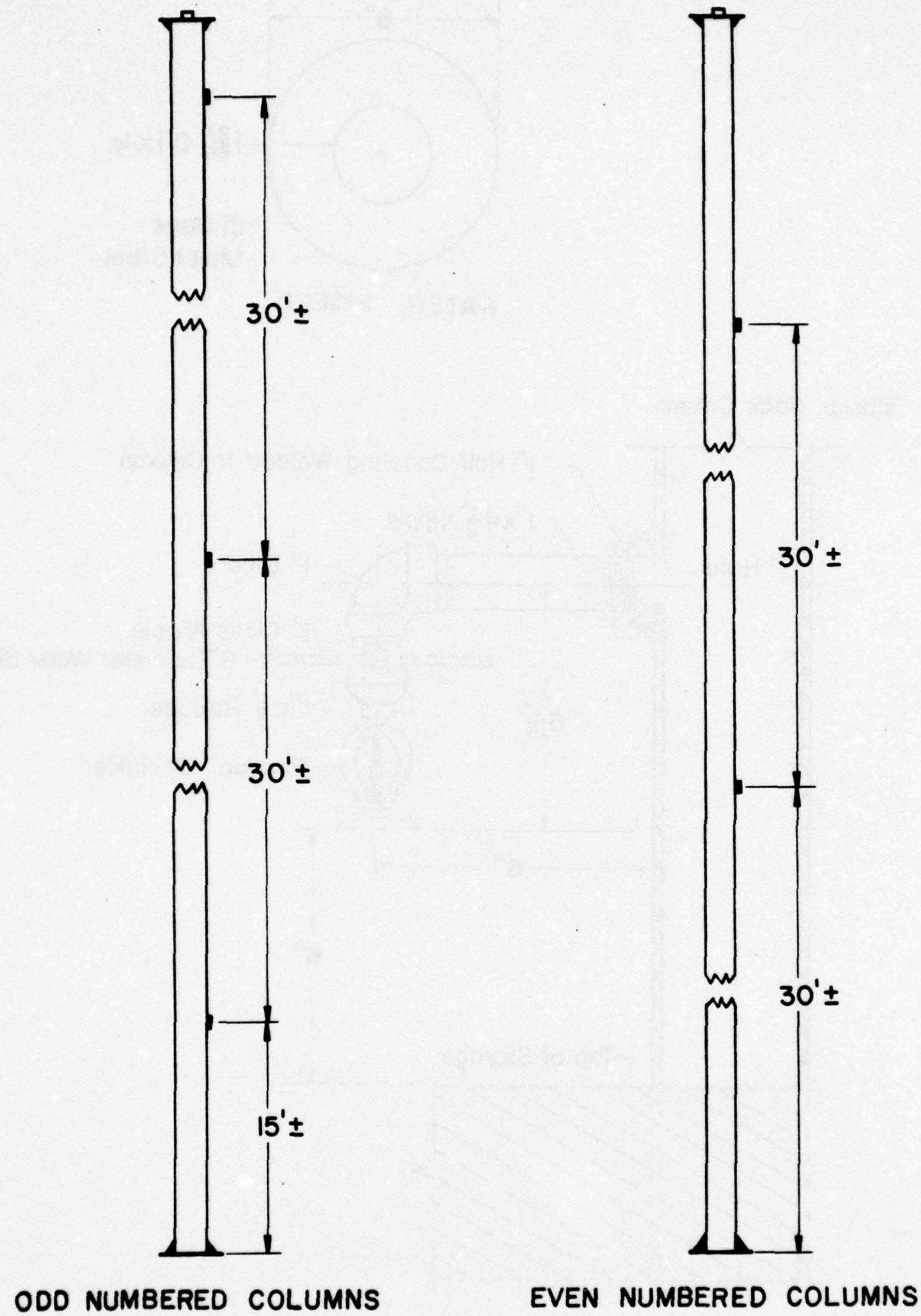


Figure. No. 8. Fabrication of Inside Tubular Rack Columns to be used as Water Conductors.

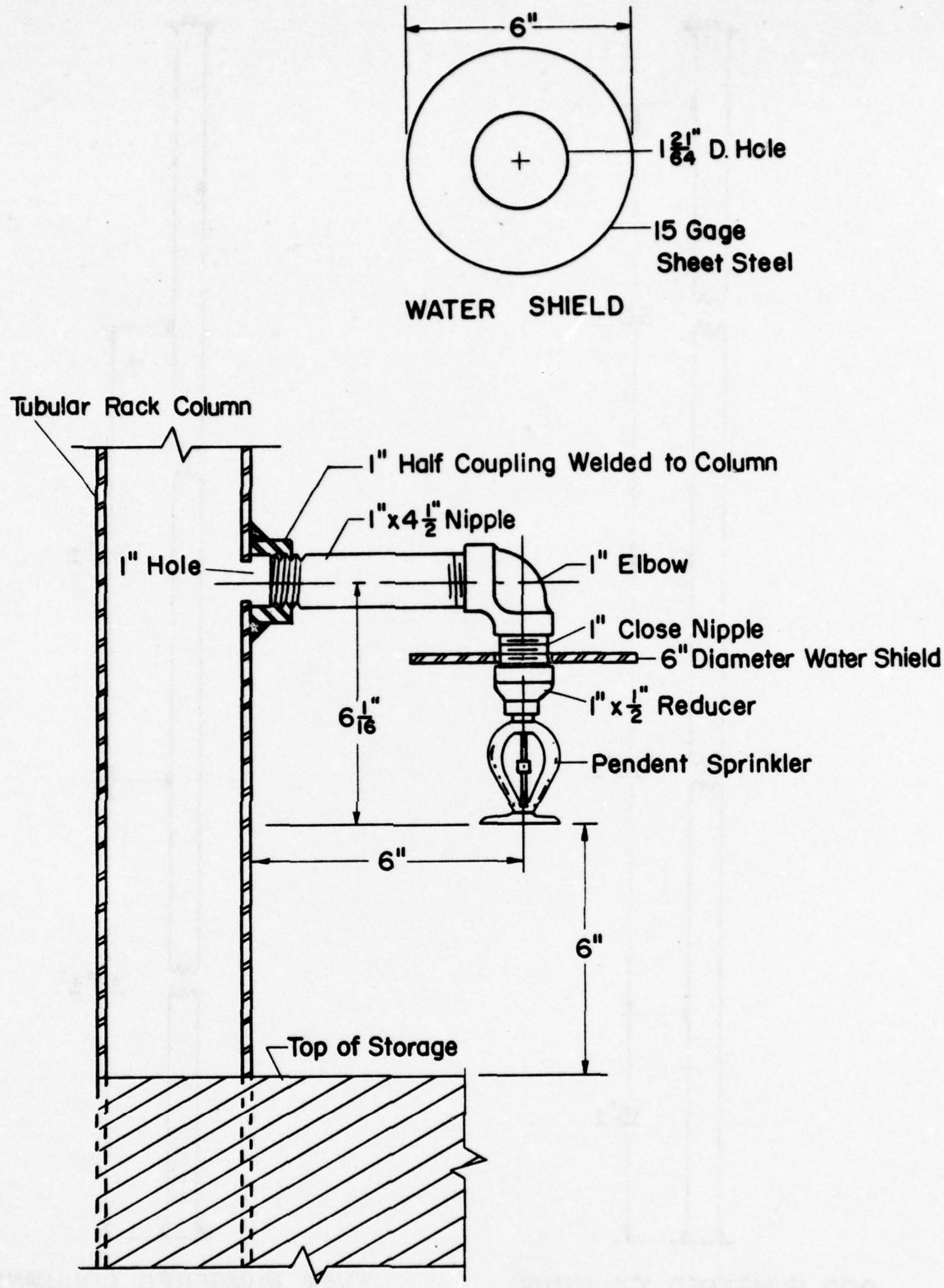


Figure No. 9. Detail of Face Sprinkler Assembly and Connection to Rack Column.

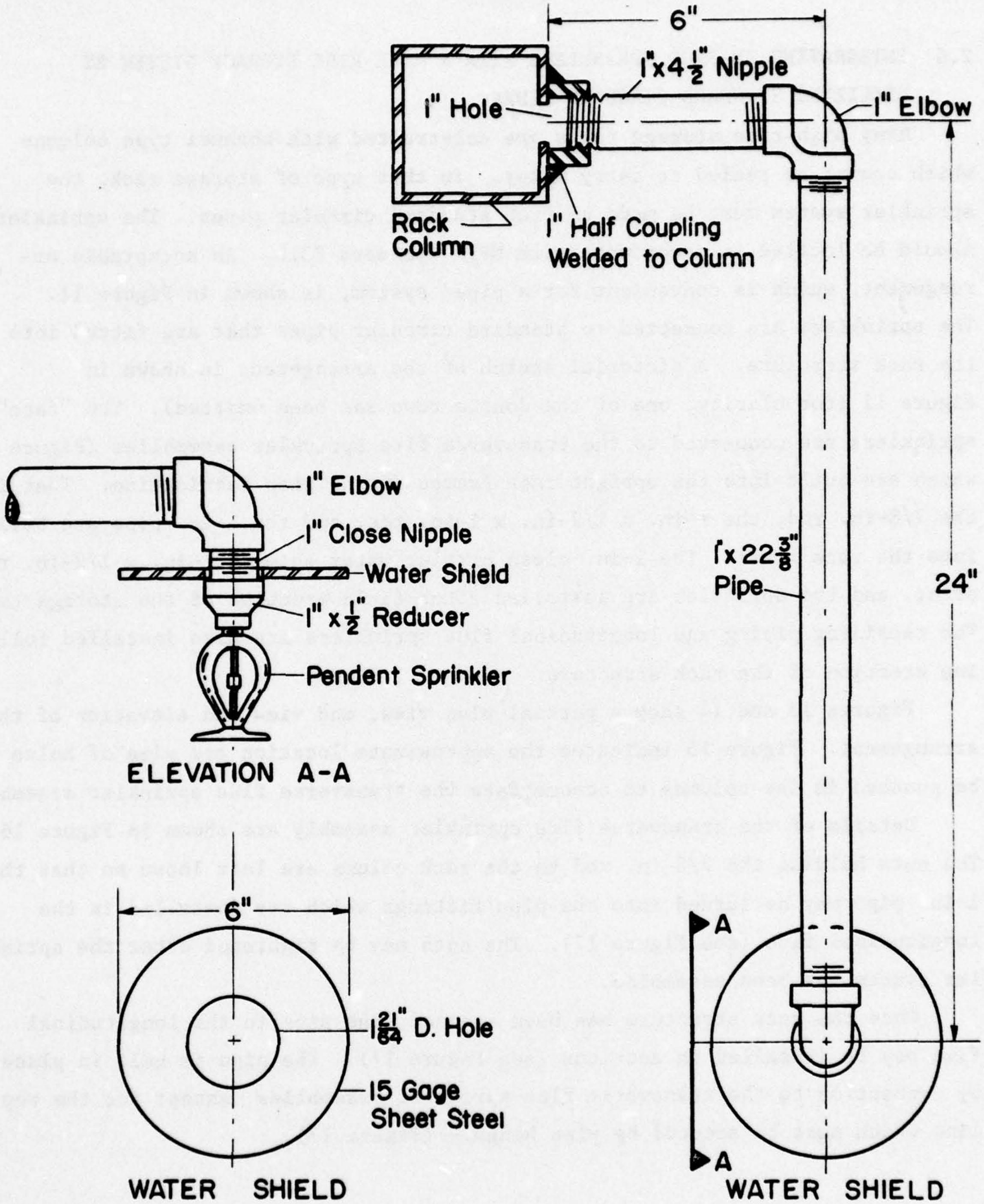


Figure No. 10. Detail of Longitudinal Flue Sprinkler Assembly and Connection to Rack Column.

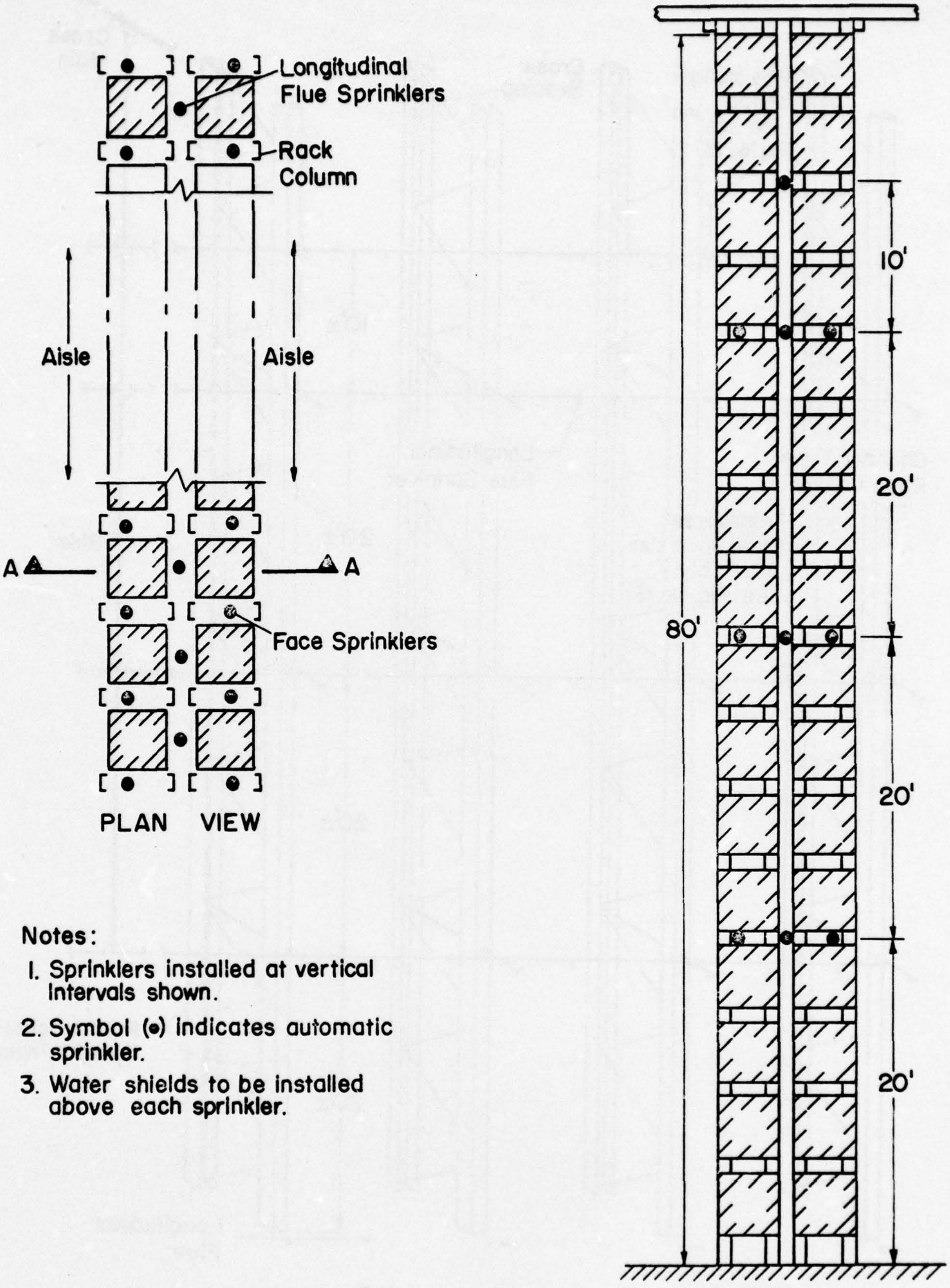
2.6 INTEGRATING IN-RACK SPRINKLERS WITH A HIGH RISE STORAGE SYSTEM BY UTILIZING STANDARD CIRCULAR PIPES

Many high rise storage racks are constructed with channel type columns which cannot be sealed to carry water. In this type of storage rack, the sprinkler system must be made up from standard circular pipes. The sprinklers should be located in accordance with NFPA Standard 231C. An acceptable arrangement, which is convenient for a piped system, is shown in Figure 11. The sprinklers are connected to standard circular pipes that are fitted into the rack structure. A pictorial sketch of the arrangement is shown in Figure 12 (for clarity, one of the double rows has been omitted). The "face" sprinklers are connected to the transverse flue sprinkler assemblies (Figure 16) which are built into the upright rack frames during shop fabrication. That is, the 7/8-in. rod, the 1-in. x 1/2-in. x 1-in. tee, and the 1-in. pipe are built into the rack frame. The 1-in. close nipple, water shield, 1-in. x 1/2-in. reducer, and the sprinkler are installed after field erection of the storage rack. The remaining piping and longitudinal flue sprinklers are also installed following erection of the rack structure.

Figures 13 and 14 show a partial plan view, end view and elevation of the arrangement. Figure 15 indicates the approximate location and size of holes to be punched in the columns to accommodate the transverse flue sprinkler assemblies.

Details of the transverse flue sprinkler assembly are shown in Figure 16. The nuts holding the 7/8-in. rod to the rack column are left loose so that the 1-in. pipe may be turned into the pipe fittings which are installed in the longitudinal flue (see Figure 17). The nuts may be tightened after the sprinkler system has been assembled.

Once the rack structure has been erected, the pipe in the longitudinal flue may be installed in sections (see Figure 17). The pipe is held in place by connection to the transverse flue sprinkler assemblies, except for the top line which must be secured by pipe hangers (Figure 17).



Notes:

1. Sprinklers installed at vertical intervals shown.
2. Symbol (•) indicates automatic sprinkler.
3. Water shields to be installed above each sprinkler.

Figure No. 11. Location of In-Rack Sprinklers for Integrated System Utilizing Standard Circular Pipes.

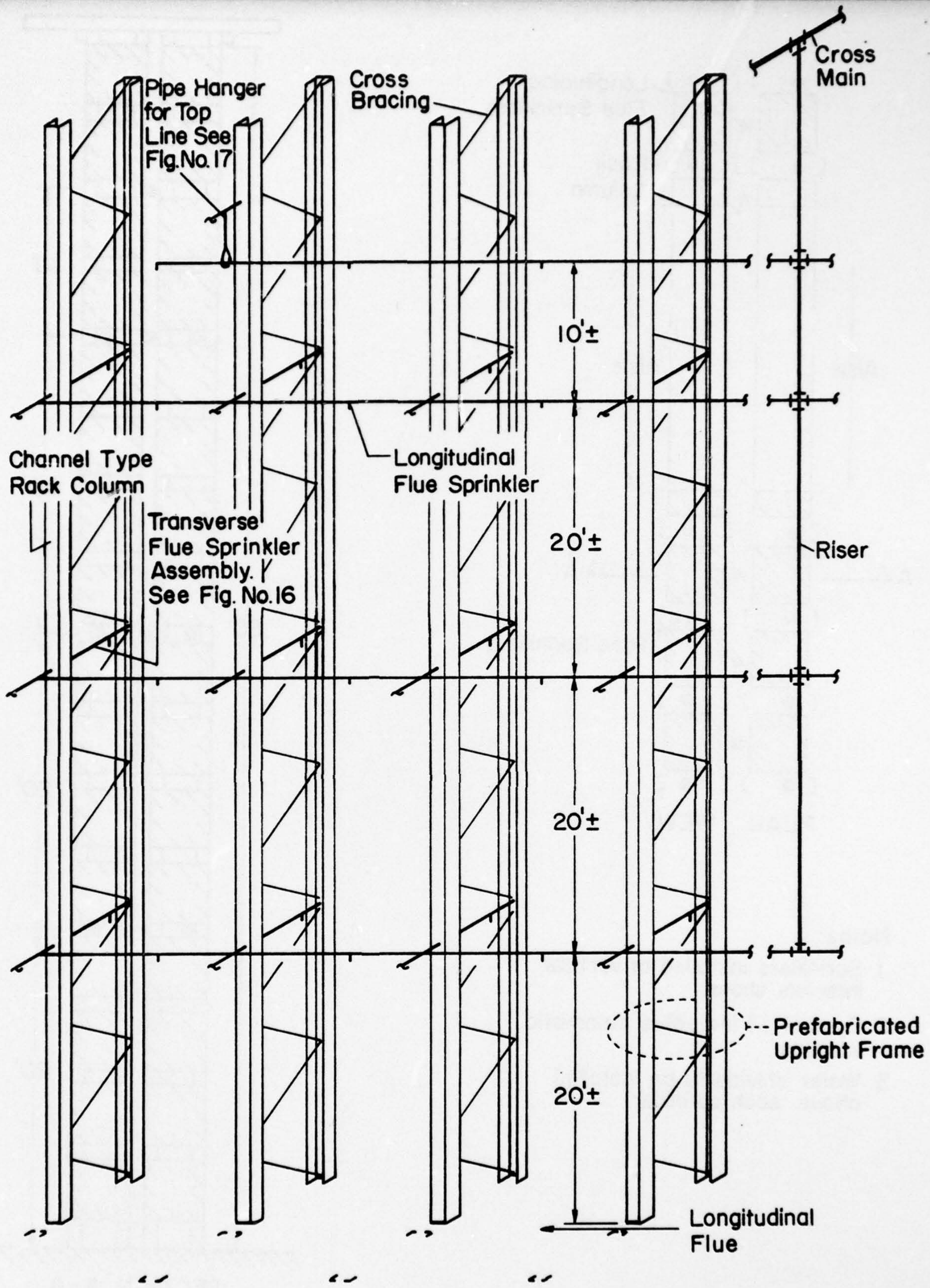


Figure No. 12. Pictorial Sketch of Integrated Sprinkler System Utilizing Standard Circular Pipes.

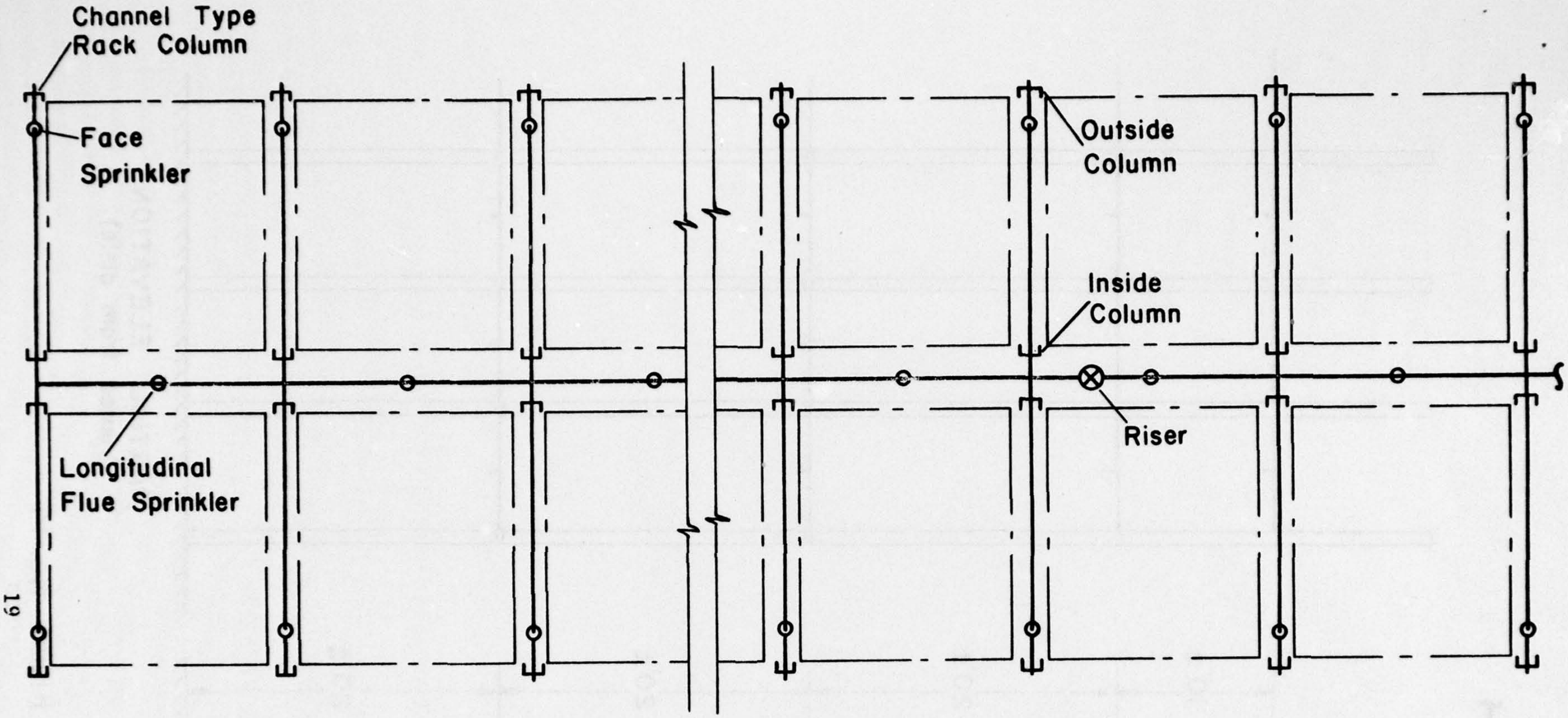


Figure. No. 13. Partial Plan View of Integrated Sprinkler System Utilizing Standard Circular Pipes.

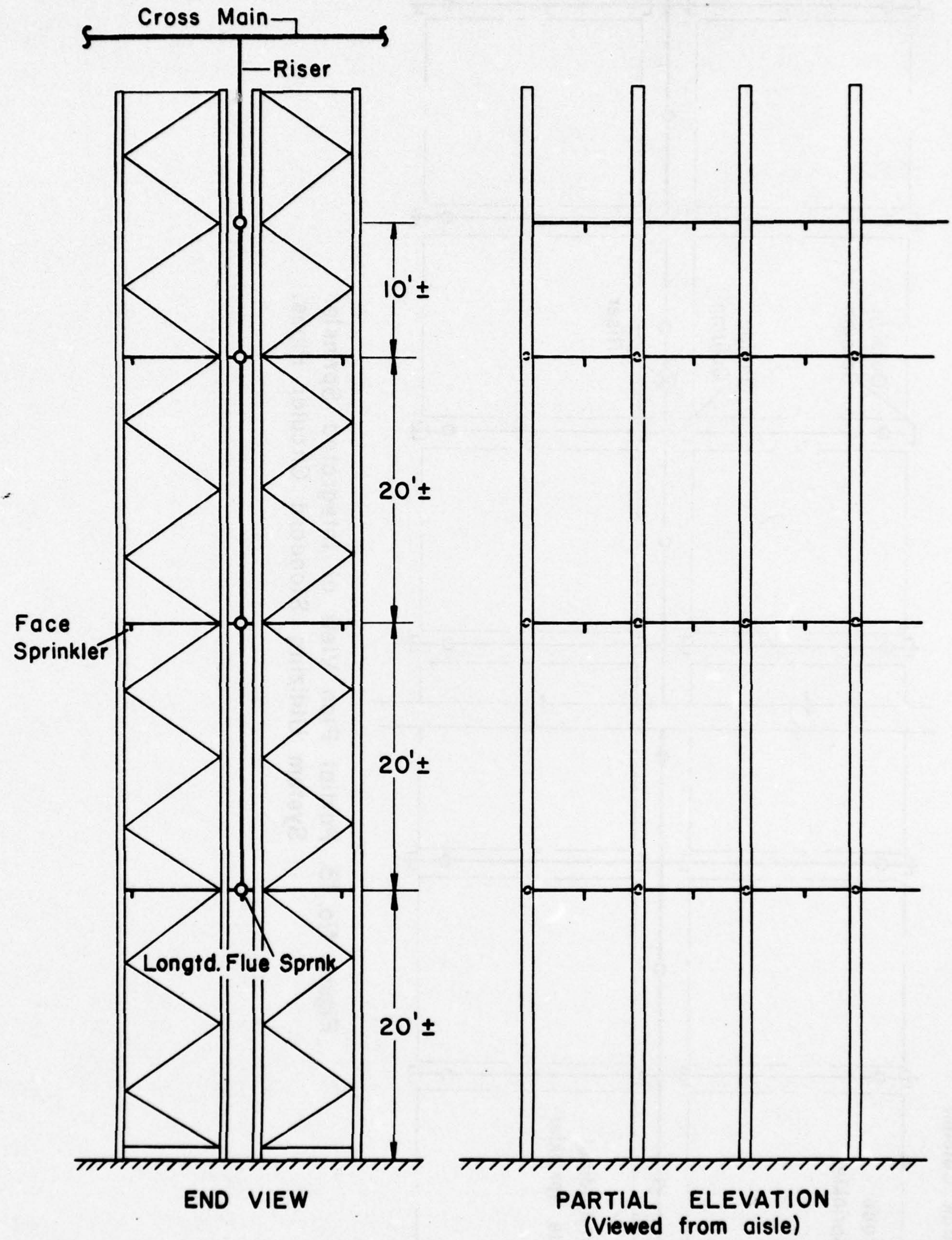

Cross Main
Riser
10'±
20'±
20'±
20'±
Face Sprinkler
Longtd. Flue Sprnk
END VIEW
PARTIAL ELEVATION
(Viewed from aisle)

Figure. No. 14

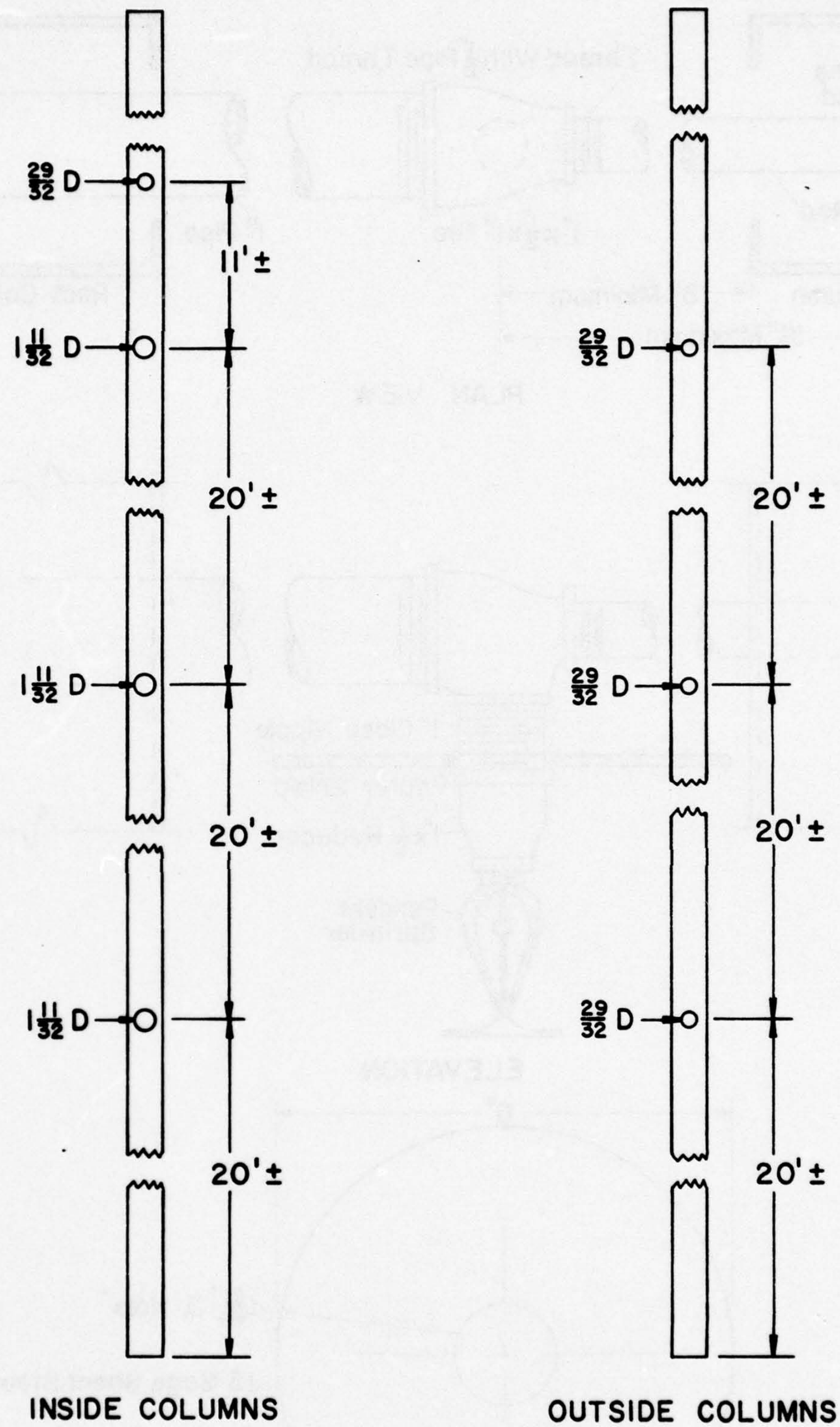


Figure. No. 15. Fabrication of Channel Type Columns to Accommodate Pipes and Rods

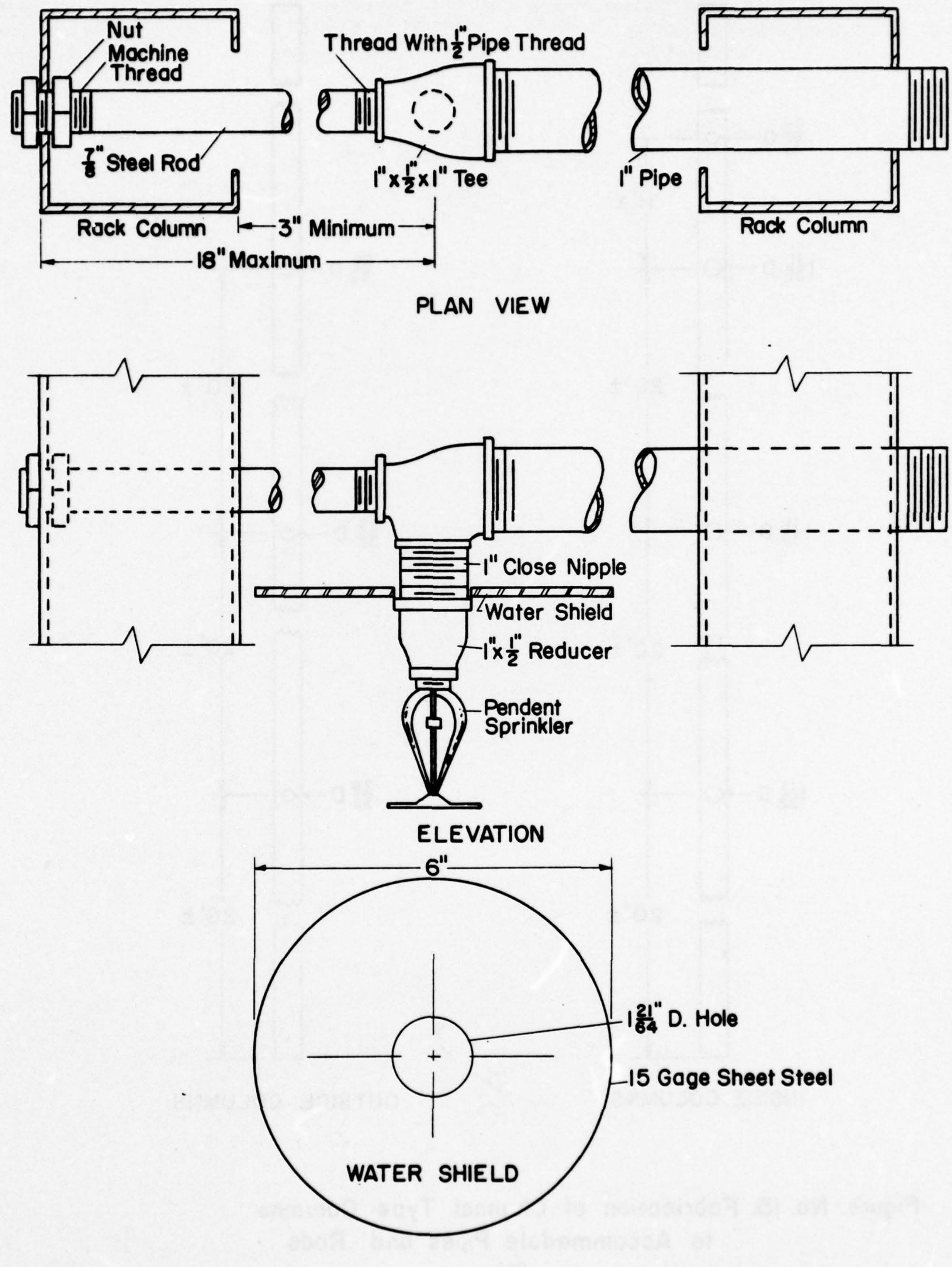
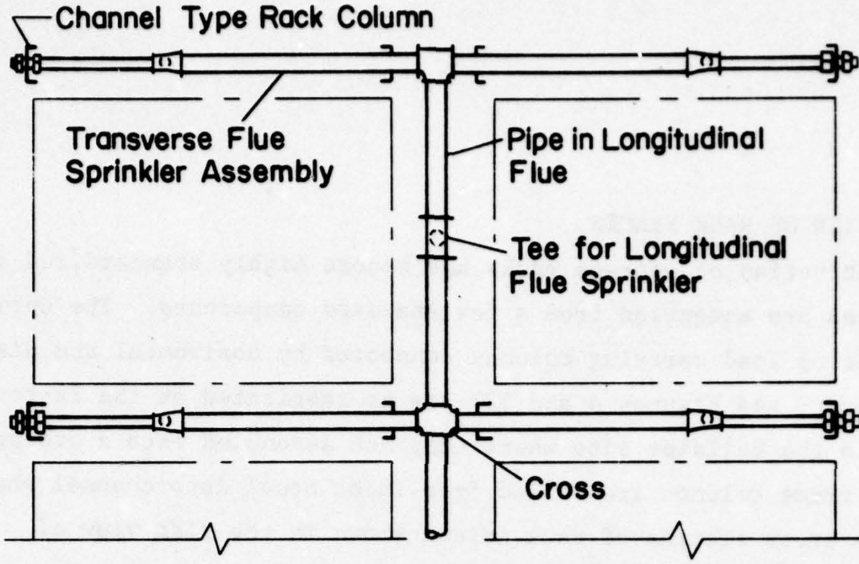
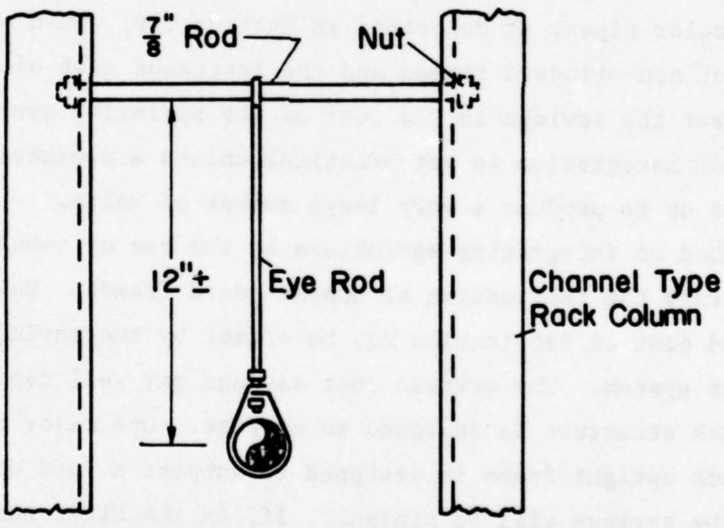


Figure No. 16. Detail of Transverse Flue Sprinkler Assembly



Detail Showing Connection of Transverse Flue Sprinkler Assembly to Pipe in Longitudinal Flue



Detail of Pipe Hangers for Top Line

Figure No. 17.

2.7 FABRICATION OF RACK FRAMES

The construction of storage racks has become highly standardized and most rack structures are assembled from a few standard components. The upright frames (a pair of load carrying columns connected by horizontal and diagonal bracing members - see Figures 4 and 12) are prefabricated at the factory and transported to the building site where they are assembled into a storage system. The frame columns are rolled from sheet steel into channel shaped sections (see cross section of rack column shown in the plan view of Figure 16). Holes are punched into the columns on 3-in. centers for connecting support members at any multiple of 3-in.

A relatively few standard frame sizes are produced, but they have sufficient flexibility to meet a very large number of storage requirements. Non-standard frames may be fabricated, but the necessary tooling changes may cause a substantial increase in the cost of a storage system.

The method of integrating sprinklers into a storage system by utilizing standard circular pipes, as described in Section 2.6, would necessitate the fabrication of non-standard frames and the increased cost of fabrication would probably offset the savings in the cost of the sprinkler system. Therefore, this method of integration is not practical unless a production line is specially set up to produce a very large number of units.

The method of integrating sprinklers by the use of tubular columns will also necessitate the fabrication of non-standard frames. However, in this case the increased cost of fabrication may be offset by the savings in the cost of the sprinkler system. The overall cost savings may well depend on the load which the rack structure is designed to support. One major manufacturer indicated, if each upright frame is designed to support a load of less than 60,000 lb, the savings will be minimal. If, on the other hand, each frame is designed to carry a load exceeding 60,000 lb, the cost savings will be substantial. The reason is that loads exceeding 60,000 lb per upright frame will require the use of tubular columns for reasons of strength alone. The increased cost of fabrication chargeable to the attachment of the plates and couplings will therefore be minimized.

III

HYDRAULIC ANALYSES OF INTEGRATED IN-RACK SPRINKLER SYSTEMS

The flow and pressure required to supply in-rack sprinklers will depend on the characteristic of the available water supply, the sprinkler system pipe sizes and the size of the rack being protected. Usually, the pipe sizes are selected to match a known water supply characteristic. Since both the water supply characteristic and rack size can vary over wide limits, it is not possible to perform a general analysis that is applicable to a large number of cases. However, the purpose of this section of the study is to compare the hydraulic performance of the two integrated systems described in Sections 2.5 and 2.6 to the performance of a conventional system. A valid comparison can be made by selecting a specific rack structure for study. Therefore, the high rise storage system shown in Figures 1 and 3 has been chosen as a basis for the analyses.

3.1 ANALYSIS OF A CONVENTIONAL SYSTEM

A conventional system would be similar in design to the integrated system described in Section 2.6 and shown in Figure 12, except all piping would be installed following erection of the rack structure. The mechanical details of installation would, of course, differ; but the two systems would be hydraulically similar. Therefore, the calculations outlined in Section 3.2 will apply equally well to a conventional system.

3.2 ANALYSIS OF AN INTEGRATED SYSTEM UTILIZING STANDARD CIRCULAR PIPES

The piping configuration is assumed to be as shown in Figure 12. Plan views of the top two levels of sprinklers are shown in Figure 18.

According to NFPA Standard No. 231-C, sprinklers in racks over 25 ft high shall discharge at a pressure of not less than 30 psi. The water demand for in-rack sprinklers protecting a Class IV commodity shall be based on the

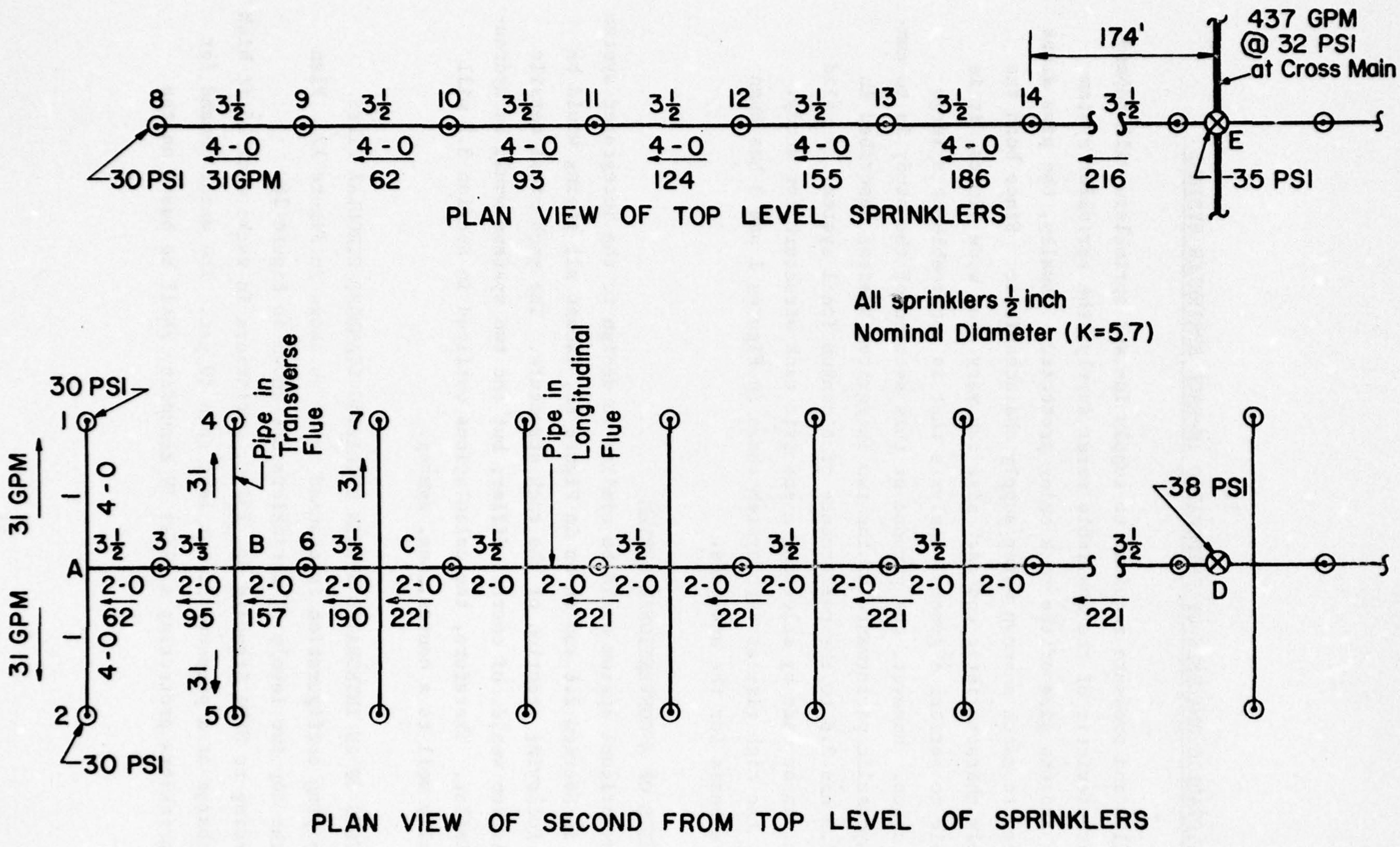

437 GPM
@ 32 PSI
at Cross Main
174'
8
9
10
11
12
13
14
E
30 PSI
35 PSI
4-0
31GPM
62
93
124
155
186
216
$3\frac{1}{2}$
PLAN VIEW OF TOP LEVEL SPRINKLERS
All sprinklers $\frac{1}{2}$ inch
Nominal Diameter (K=5.7)
30 PSI
1
2
3
4
5
6
7
A
B
C
D
31 GPM
31
Pipe in Transverse Flue
Pipe in Longitudinal Flue
38 PSI
$3\frac{1}{3}$
2-0
62
95
157
190
221
PLAN VIEW OF SECOND FROM TOP LEVEL OF SPRINKLERS

Figure. No. 18

simultaneous operation of the most hydraulically remote 14 sprinklers (seven on each of the top two levels). This means that the seven sprinklers on each of the top two levels must be chosen in a way that will produce the maximum demand.

The small lateral pipes feeding the transverse flue sprinklers will be 1-in. nominal diameter, as shown in Figure 18. The large pipe in the longitudinal flue will vary in size depending on the water supply characteristic. However, for the purposes of this analysis a uniform diameter of 3 1/2 in. was assumed.

According to NFPA requirements, the most remote sprinklers (numbered 1, 2 and 8 in Figure 18) are assumed to be discharging at a pressure of 30 psi. The calculations are carried out in a standard manner (see NFPA Standard No. 13 for details) and result in a demand of 437 gpm at a pressure of 32 psi at the overhead cross main.

The flows in gpm through the various sections of pipe are indicated by arrows in Figure 18. Pressures in psi are also shown at several points in the system. The detailed calculations are given in Table 1.

3.3 ANALYSIS OF AN INTEGRATED SYSTEM UTILIZING TUBULAR RACK COLUMNS AS WATER CONDUCTORS

The piping and tubular rack columns are assumed to be arranged as shown in Figure 4. The pipe connecting the sprinklers to the columns is 1-in. nominal diameter. The columns are assumed to be square in cross section and 4 in. on a side. The size of the feed pipes will vary depending on the water supply characteristic; but, in order to compare the demand for this system with that for the system using standard circular pipes, a uniform diameter of 3 1/2 in. was assumed. Plan views of the system are shown in Figure 19.

The requirements for end head pressure and the number of operating sprinklers are the same as specified in Section 3.2. The seven sprinklers on each of the top two levels have been selected in a way that will produce the maximum demand.

HYDRAULIC CALCULATIONS

FM

OF INTEGRATED SYSTEM UTILIZING STANDARD CIRCULAR PIPES

FOR	SHEET	OF	INDEX NO.
NavFac Cont. No. N00025-74-C-0023	1	3	22415
See Fig. No. 18 For Station Points	BY		DATE 7/5/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN GPM	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES
A	q Q 62.44	$3\frac{1}{2}$		Lgth Fit Tot 2	.003	Pt 32.64 Pe Pf .01	Pt Pv Pn	
3	q 32.57 Q 95.01	$3\frac{1}{2}$		Lgth Fit Tot 2	.006	Pt 32.65 Pe Pf .01	Pt Pv Pn	$q = 5.7\sqrt{32.65}$
B	q 62.41 Q 157.42	$3\frac{1}{2}$		Lgth Fit Tot 2	.015	Pt 32.66 Pe Pf .03	Pt Pv Pn	$q = 10.92\sqrt{32.66}$ See Sheet 3
6	q 32.59 Q 190.01	$3\frac{1}{2}$		Lgth Fit Tot 2	.022	Pt 32.69 Pe Pf .04	Pt Pv Pn	$q = 5.7\sqrt{32.69}$
C	q 31.24 Q 221.25	$3\frac{1}{2}$		Lgth Fit Tot 192	.029	Pt 32.73 Pe Pf 5.57	Pt Pv Pn	$q = 5.46\sqrt{32.73}$ See Sheet 3
D	q - Q 221.25	$3\frac{1}{2}$	CR-17	Lgth 10 Fit 17 Tot 27	.029	Pt 38.30 Pe -4.33 Pf .78	Pt Pv Pn	$P_e = .433X10$ $= 4.33$
E	q 215.71 Q 436.96	$3\frac{1}{2}$	T-17	Lgth 15 Fit 17 Tot 32	.104	Pt 34.75 Pe -6.50 Pf 3.33	Pt Pv Pn	$P_e = .433X15$ $= 6.50$ q from Sheet 2
X-Main	q Q			Lgth Fit Tot		Pt 31.58 Pe Pf	Pt Pv Pn	At Cross Main

The Total Demand For Rack Sprinklers Is 437 GPM at 32 PSI At The Cross Main (See Figure No. 18)

HYDRAULIC CALCULATIONS

FM

FACTORY MUTUAL ENGINEERING ASSOCIATION

FOR	SHEET	OF	INDEX NO.
NavFac	2	3	22415
	BY		DATE 7/5/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN G P M	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES 1/2 A.S. K = 5.7
8	q 31.22	3 1/2		Lgth		Pt 30	Pt	$q = 5.7\sqrt{30}$
				Fit		Pe	Pv	
	Q 31.22			Tot 4	.001	Pf	Pn	
9	q 31.22	3 1/2		Lgth		Pt 30.001	Pt	$q = 5.7\sqrt{30.001}$
				Fit		Pe	Pv	
	Q 62.44			Tot 4	.003	Pf .01	Pn	
10	q 31.23	3 1/2		Lgth		Pt 30.01	Pt	$q = 5.7\sqrt{30.01}$
				Fit		Pe	Pv	
	Q 93.67			Tot 4	.006	Pf .02	Pn	
11	q 31.24	3 1/2		Lgth		Pt 30.03	Pt	$q = 5.7\sqrt{30.03}$
				Fit		Pe	Pv	
	Q 124.91			Tot 4	.01	Pf .04	Pn	
12	q 31.26	3 1/2		Lgth		Pt 30.07	Pt	$q = 5.7\sqrt{30.07}$
				Fit		Pe	Pv	
	Q 156.17			Tot 4	.015	Pf .06	Pn	
13	q 31.29	3 1/2		Lgth		Pt 30.13	Pt	$q = 5.7\sqrt{30.13}$
				Fit		Pe	Pv	
	Q 187.46			Tot 4	.021	Pf .08	Pn	
14	q 31.33	3 1/2	CR-17	Lgth 174		Pt 30.21	Pt	$q = 5.7\sqrt{30.21}$
				Fit 17		Pe	Pv	
	Q 218.79			Tot 191	.029	Pf 5.54	Pn	
E	q			Lgth		Pt 35.75	Pt	$q = 218.79\sqrt{\frac{34.75}{35.75}}$
				Fit		Pe	Pv	$= 215.71$
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	Flow Corrected For Press. = 215.71 @ E
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	

HYDRAULIC CALCULATIONS

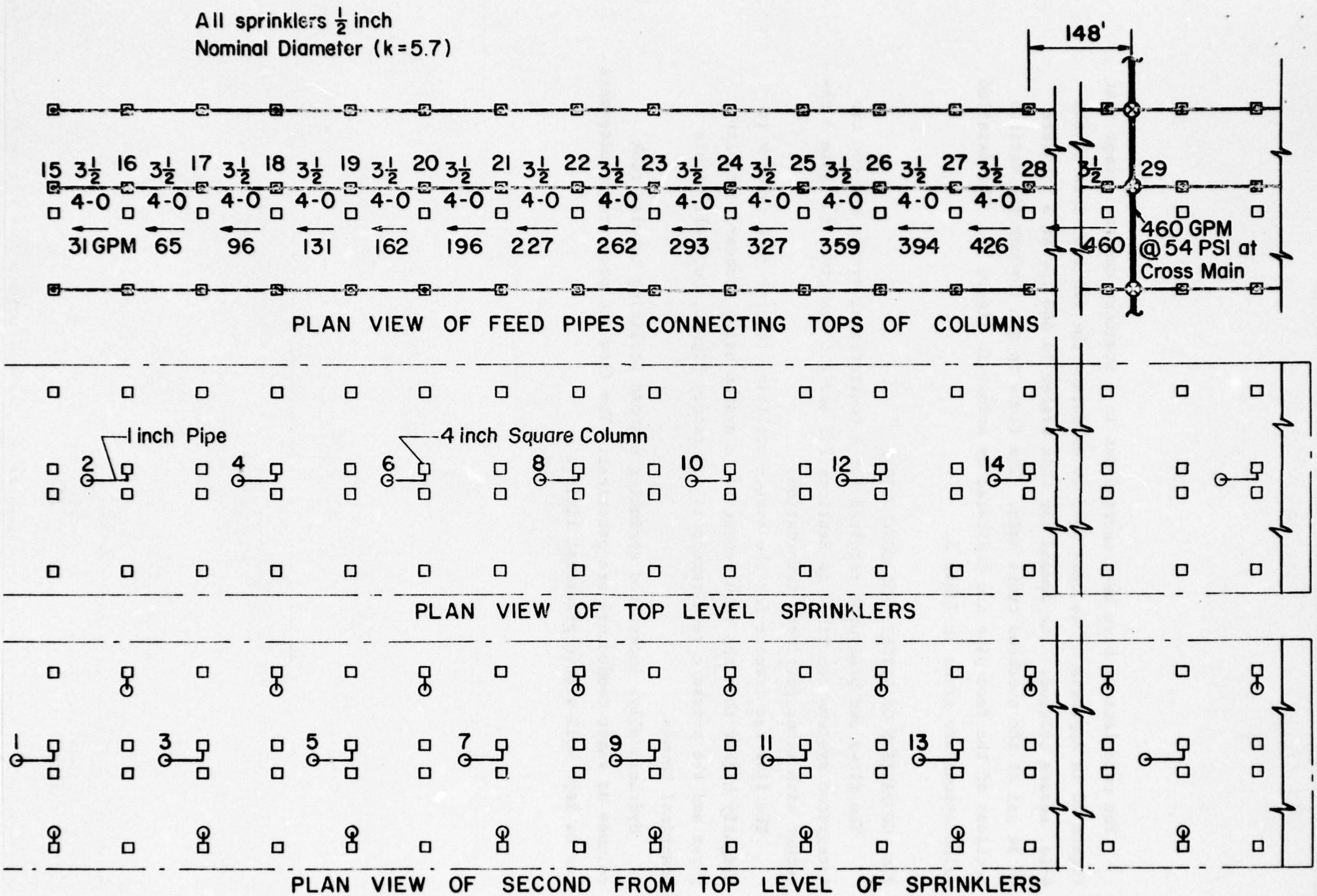
FM

FACTORY MUTUAL ENGINEERING ASSOCIATION

FOR	SHEET	OF	INDEX NO.
NavFac	3	3	22415
	BY		DATE
K Factor For Branch Line 2nd Level			7/5/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN G P M	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES 1/2" A.S. K = 5.7
1	q 31.22	1	T-5	Lgth 4.0		Pt 30	Pt	$q = 5.7\sqrt{30}$
				Fit 5		Pe	Pv	
	Q 31.22			Tot 9.0	.293	Pf 2.64	Pn	
A	q			Lgth		Pt 32.64	Pt	$K = \frac{31.22}{\sqrt{32.64}} = 5.46$
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	For Single Line
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	For Double Line
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	$K = \frac{2X31.22}{\sqrt{32.64}} = 10.9$[illegible]
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	

Printed in U. S. A.



All sprinklers 1/2 inch
Nominal Diameter (k=5.7)
148'
15 3 1/2 16 3 1/2 17 3 1/2 18 3 1/2 19 3 1/2 20 3 1/2 21 3 1/2 22 3 1/2 23 3 1/2 24 3 1/2 25 3 1/2 26 3 1/2 27 3 1/2 28 3 1/2 29
4-0
31 GPM 65 96 131 162 196 227 262 293 327 359 394 426 460
460 GPM @ 54 PSI at Cross Main
PLAN VIEW OF FEED PIPES CONNECTING TOPS OF COLUMNS
1 inch Pipe
4 inch Square Column
2 4 6 8 10 12 14
PLAN VIEW OF TOP LEVEL SPRINKLERS
1 3 5 7 9 11 13
PLAN VIEW OF SECOND FROM TOP LEVEL OF SPRINKLERS

Figure. No. 19

The calculations have been carried out in a standard manner, except that Figure 20 in Appendix A has been used to calculate the friction loss in the 4-in. square columns. The demand for this system is 460 gpm at a pressure of 54 psi at the overhead cross main. The flows in gpm through the various sections of the feed pipe are indicated by arrows in Figure 19. The detailed calculations are given in Table 2.

3.4 COMPARISON OF RESULTS AND CONCLUSIONS

The flows and pressures required for a conventional system and the two integrated systems described in Sections 2.5 and 2.6 are given in Table 3 together with other pertinent information.

The flow requirement for the system utilizing tubular rack columns is slightly higher than the requirement for a system using standard circular pipes and the pressure requirement is moderately higher, but well within practical bounds.

Hydraulically, integrated sprinkler systems utilizing tubular rack columns as water conductors are practical. The flow and pressure requirements can be kept well within practical limits.

TABLE 2

HYDRAULIC CALCULATIONS

OF INTEGRATED SYSTEM UTILIZING TUBULAR RACK COLUMNS

FM

FOR	SHEET	INDEX NO.
NavFac Cont. No. N00025-74-C-0023	SHEET 1 OF 3	22415
See Fig. No. 19 for Station Points	BY	DATE 6/27/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN G P M	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES
15	q Q 31.22	$3\frac{1}{2}$		Lgth Fit Tot 4	.001	Pt 31.19 Pe Pf .004	Pt Pv Pn	K for Sprink. Assemb. & Sq. Column = 5.4
16	q 34.08 Q 65.30	$3\frac{1}{2}$		Lgth Fit Tot 4	.003	Pt 31.19 Pe ~~9.09~~ Pf .01	Pt 40.28 Pv Pn	$q = 5.4\sqrt{40.28}$ $= 34.8$
17	q 31.22 Q 96.52	$3\frac{1}{2}$		Lgth Fit Tot 4	.006	Pt 31.20 Pe ~~2.60~~ Pf .02	Pt 33.80 Pv Pn	q = 31.22
18	q 34.10 Q 130.62	$3\frac{1}{2}$		Lgth Fit Tot 4	.011	Pt 31.22 Pe ~~9.09~~ Pf .04	Pt 40.31 Pv Pn	q = 34.10
19	q 31.25 Q 161.87	$3\frac{1}{2}$		Lgth Fit Tot 4	.016	Pt 31.26 Pe ~~2.60~~ Pf .06	Pt 33.86 Pv Pn	q = 31.25
20	q 34.14 Q 196.01	$3\frac{1}{2}$		Lgth Fit Tot 4	.023	Pt 31.32 Pe ~~9.09~~ Pf .09	Pt 40.41 Pv Pn	q = 34.14
21	q 31.32 Q 227.33	$3\frac{1}{2}$		Lgth Fit Tot 4	.03	Pt 31.41 Pe ~~2.60~~ Pf .12	Pt 34.01 Pv Pn	q = 31.32
22	q 34.23 Q 261.56	$3\frac{1}{2}$		Lgth Fit Tot 4	.04	Pt 31.53 Pe ~~9.09~~ Pf .16	Pt 40.62 Pv Pn	q = 34.23
23	q 31.45 Q 293.01	$3\frac{1}{2}$		Lgth Fit Tot 4	.049	Pt 31.69 Pe ~~2.60~~ Pf .20	Pt 34.29 Pv Pn	q = 31.45
24	q 34.37 Q 327.38	$3\frac{1}{2}$		Lgth Fit Tot 4	.06	Pt 31.89 Pe ~~9.09~~ Pf .24	Pt 40.98 Pv Pn	q = 34.37
25	q 31.65 Q 359.03	$3\frac{1}{2}$		Lgth Fit Tot 4	.071	Pt 32.13 Pe ~~2.60~~ Pf .28	Pt 34.73 Pv Pn	q = 31.65

FM

HYDRAULIC CALCULATIONS

FACTORY MUTUAL ENGINEERING ASSOCIATION

FOR	SHEET	INDEX NO.
NavFac	2 OF 3	22415
	BY	DATE 6/27/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN G P M	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES
26	q 34.60	$3\frac{1}{2}$		Lgth		Pt 32.41	Pt 41.50	q = 34.60
				Fit		Pe 9.09	Pv	
	Q 393.63			Tot 4	.086	Pf .34	Pn	
27	q 31.93	$3\frac{1}{2}$		Lgth		Pt 32.75	Pt 35.35	q = 31.93
				Fit		Pe 2.60	Pv	
	Q 425.56			Tot 4	.098	Pf .39	Pn	
28	q 34.90	$3\frac{1}{2}$	2T-34	Lgth 150		Pt 33.14	Pt 42.23	q = 34.90
				Fit 34		Pe 9.09	Pv	
	Q 460.46			Tot 184	.114	Pf 20.98	Pn	
29	q			Lgth		Pt 54.12	Pt	At Cross Main
				Fit		Pe	Pv	
	Q			Tot		Pf	Pn	

The Total Demand For Rack Sprinklers Is 460 Gpm at 54 PSI

At The Cross Main (See Fig. No. 19).

FM

HYDRAULIC CALCULATIONS

FACTORY MUTUAL ENGINEERING ASSOCIATION

FOR NavFac — SHEET 3 OF 3 — INDEX NO. 22415

K Factor For Sprink. Assemb. & 4" Sq. Col. — BY — DATE 6/27/75

SPKR. OR NOZZLE IDENT. & LOCATION	FLOW IN GPM	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT. C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES 1/2" A.S. K=5.7
2	q 31.22 Q 31.22	1	T-5 E-2	Lgth 2.5 Fit 7 Tot 9.5	.293	Pt 30 Pe Pf 2.78	Pt Pv Pn	$q = 5.7\sqrt{30}$
	q Q 31.22	4 Sq.	Enlrg. 11	Lgth 5 Fit 11 Tot 16	.00042	Pt 32.78 Pe Pf 0.01	Pt Pv Pn	
	q Q 31.22	2	T-10	Lgth 1 Fit 10 Tot 11	.011	Pt 32.79 Pe Pf 0.12	Pt Pv Pn	
16	q Q			Lgth Fit Tot		Pt 32.91 Pe Pf	Pt Pv Pn	At Feed Pipe $K = \frac{31.22}{\sqrt{32.91}} = 5.4$
	q Q			Lgth Fit Tot		Pt Pe Pf	Pt Pv Pn	
1	q 31.22 Q 31.22	1	T-5 E-2	Lgth 2.5 Fit 7 Tot 9.5	.293	Pt 30 Pe Pf 2.78	Pt Pv Pn	$q = 5.7\sqrt{30}$
	q Q 31.22	4 Sq.	Enlrg. 11	Lgth 20 Fit 11 Tot 31	.00042	Pt 32.78 Pe Pf 0.02	Pt Pv Pn	
	q Q 31.22	2	T-10	Lgth 1 Fit 10 Tot 11	.011	Pt 32.80 Pe Pf 0.12	Pt Pv Pn	
15	q Q			Lgth Fit Tot		Pt 32.92 Pe Pf	Pt Pv Pn	At Feed Pipe $K = \frac{31.22}{\sqrt{32.92}} = 5.4$
	q Q			Lgth Fit Tot		Pt Pe Pf	Pt Pv Pn	
	q Q			Lgth Fit Tot		Pt Pe Pf	Pt Pv Pn	

TABLE 3

COMPARISON OF INTEGRATED SPRINKLER SYSTEMS

WITH CONVENTIONAL SYSTEM

	Rack Length ft	Rack Height ft	Commodity Class	No. Open Sprinklers	End Head Pressure psi	Total Flow gpm	Total Pressure psi*
Conventional System	400	80	IV	14	30	437	32
Integrated System With Circular Pipes	400	80	IV	14	30	437	32
Integrated System With Tubular Columns	400	80	IV	14	30	460	54

*These are the pressures required at the ceiling cross main for the pipe sizes shown in Figures 18 and 19. Friction and elevation losses must be added to these pressures in order to obtain the pressures required at ground level.

IV

COST EFFECTIVE ANALYSIS OF INTEGRATED SPRINKLER SYSTEMS

In an effort to obtain realistic comparative cost data, several rack manufacturers were first contacted. An attempt was made to determine the relative cost increase associated with the required changes in fabrication of the rack frame itself. Such changes would include the use of tubular columns as required in place of channel sections, welded fittings on the tubular columns as in Figure 10 and modifications to accommodate the feeding of water to the columns. These increased costs were then to be weighed against cost savings, if any, associated with the installation of the sprinkler system (as performed by a sprinkler contractor) such that an overall cost comparison picture could be obtained. Unfortunately, no specific cost information could be obtained from the manufacturers queried, without extensive study on their part. Cost quotations for obtaining the desired information from the manufacturers were solicited and proved to be prohibitive.

In spite of this information void, it was felt that the sprinkler system cost comparison would still provide meaningful information for a total cost comparison overview. The engineering department of Grinnell Fire Protection Systems Company, Inc. was retained to do a complete cost comparison for Factory Mutual Research Corporation's integrated design (Figures 4-10) versus a standard sprinkler system integration with identical sprinkler locations. As mentioned in Section 2.7 it was decided that the method of utilizing standard circular pipe as discussed in Section 2.6 would probably not generate practical savings and was, therefore, not included in this analysis.

The analysis and cost figures do not include consideration of the overhead protection system since the same elements would be required for both alternatives.

Attached as Appendix B is Grinnell's letter report together with their cost comparison summary sheet (Table 4), Sketch A (Figure 23) and five rack layout drawings (Figures 24-28). Based on the data in Table 4, significant cost savings appear possible with the integrated system. Unfortunately, we do not know the costs associated with the couplings and steel plates as discussed in Grinnell's letter or the increased cost of tubular stock over channel stock where required (if not already necessary due to load). However, it seems unlikely that these costs could possibly exceed half the savings noted. It should also be recognized that, if overhead and profit are a direct percentage of labor and materials, the total savings will be even greater.

V

CONCLUSIONS

1. Depending on the expected load per vertical column, the columns may require tubular stock to provide necessary support. In such cases, no additional cost would result solely as an integrated rack fire protection requirement.
2. It does not appear that a partially integrated rack fire protection system as described in Section 2.6 would result in a significant overall gain.
3. A fully integrated rack fire protection system as described in Section 2.5 is feasible and practical and would result in sprinkler system cost savings of up to 30 percent.
4. Because of the much smaller lengths of pipe involved, an integrated rack fire protection system would be less likely to sustain physical damage due 1) to equipment malfunction in a non-fire environment and 2) to falling debris in a fire condition.

APPENDIX A

FRICTION LOSS IN PIPES OF NON-CIRCULAR SECTION

Friction loss in sprinkler system piping is calculated from the William and Hazen formula. In the original form it was written

$$V = 1.318\ CR^{0.63}\ S^{0.54} \tag{1}$$

where V = mean velocity in feet per second

C = coefficient of roughness

R = hydraulic radius (the ratio of the cross sectional area of the pipe to its wetted perimeter)

S = hydraulic slope (the ratio of lost head to the pipe length)

Introducing the proper conversion factors, the equation may be written in more practical terms as,

$$P = 0.00529LQ^{1.85} \Big/ C^{1.85}\ R^{4.87} \tag{2}$$

where P = friction loss in psi

L = length of pipe in feet

Q = flow in gpm

and C and R remain as defined above.

Equation 2 may be used for a pipe of any shape because the hydraulic radius R has been retained as a factor rather than being converted to a diameter for use with circular pipes. The hydraulic radius for a circular pipe is equal to D/4 and if this value is substituted into eq (2), the more familiar form of the equation is obtained as

$$P = 4.52\ LQ^{1.85} \Big/ C^{1.85}\ D^{4.87} \tag{3}$$

where D = the diameter for a circular pipe.

With the aid of eq (2), the charts shown in Figures 20, 21 and 22 have been prepared to facilitate the calculation of friction loss in non-circular pipes. A simple example will illustrate their use. Suppose it is desired to find the friction loss per foot for a flow of 100 gpm through a smooth pipe of rectangular section measuring 2 in. by 3 in. The hydraulic radius for the pipe is

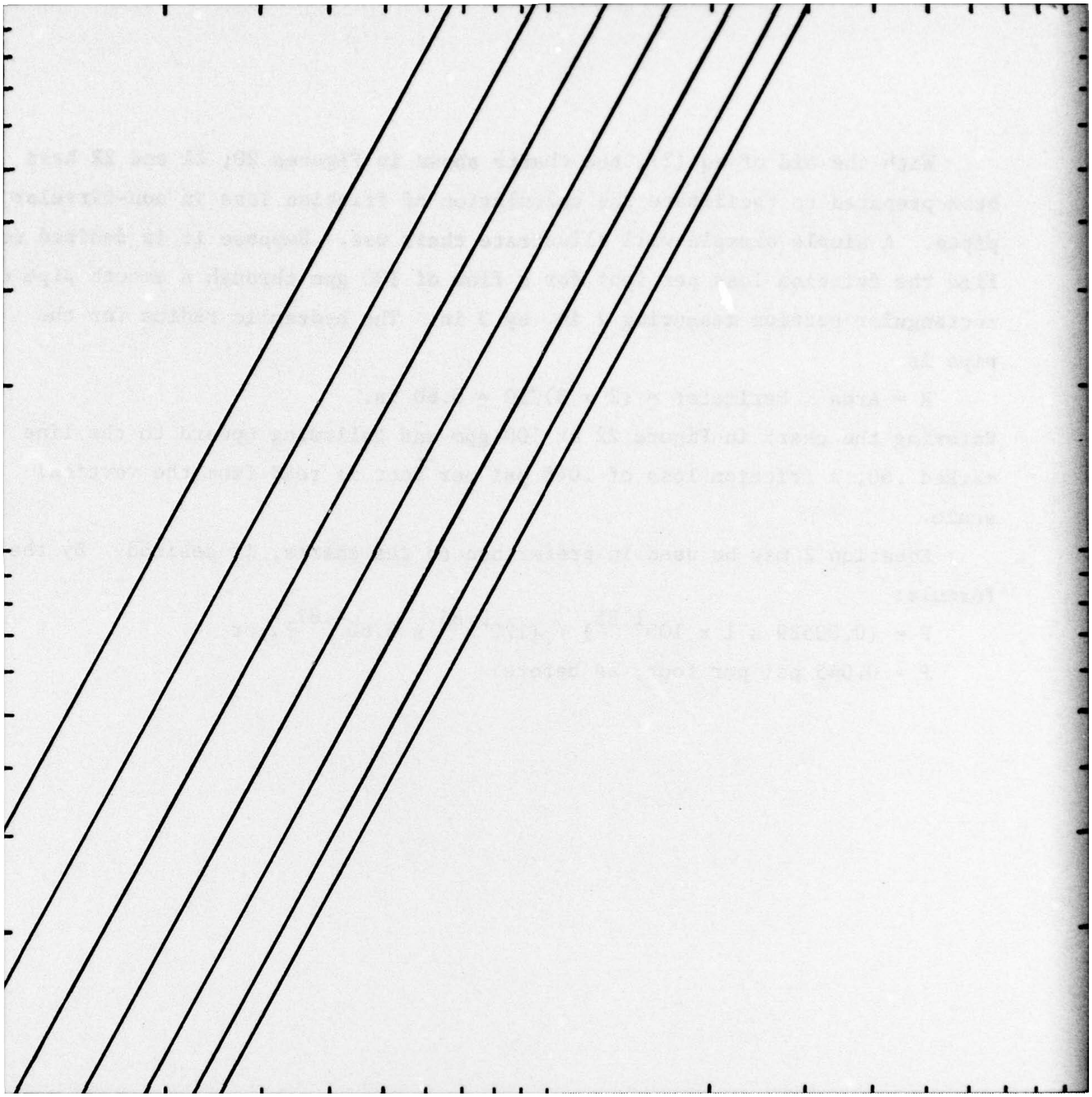
$$R = \text{Area} \div \text{Perimeter} = (2 \times 3)/10 = 0.60 \text{ in.}$$

Entering the chart in Figure 22 at 100 gpm and following upward to the line marked .60, a friction loss of .045 psi per foot is read from the vertical scale.

Equation 2 may be used in preference to the charts, if desired. By the formula:

$$P = (0.00529 \times 1 \times 100^{1.85}) / (120^{1.85} \times 0.60^{4.87}), \text{ or}$$

$$P = 0.045 \text{ psi per foot, as before.}$$



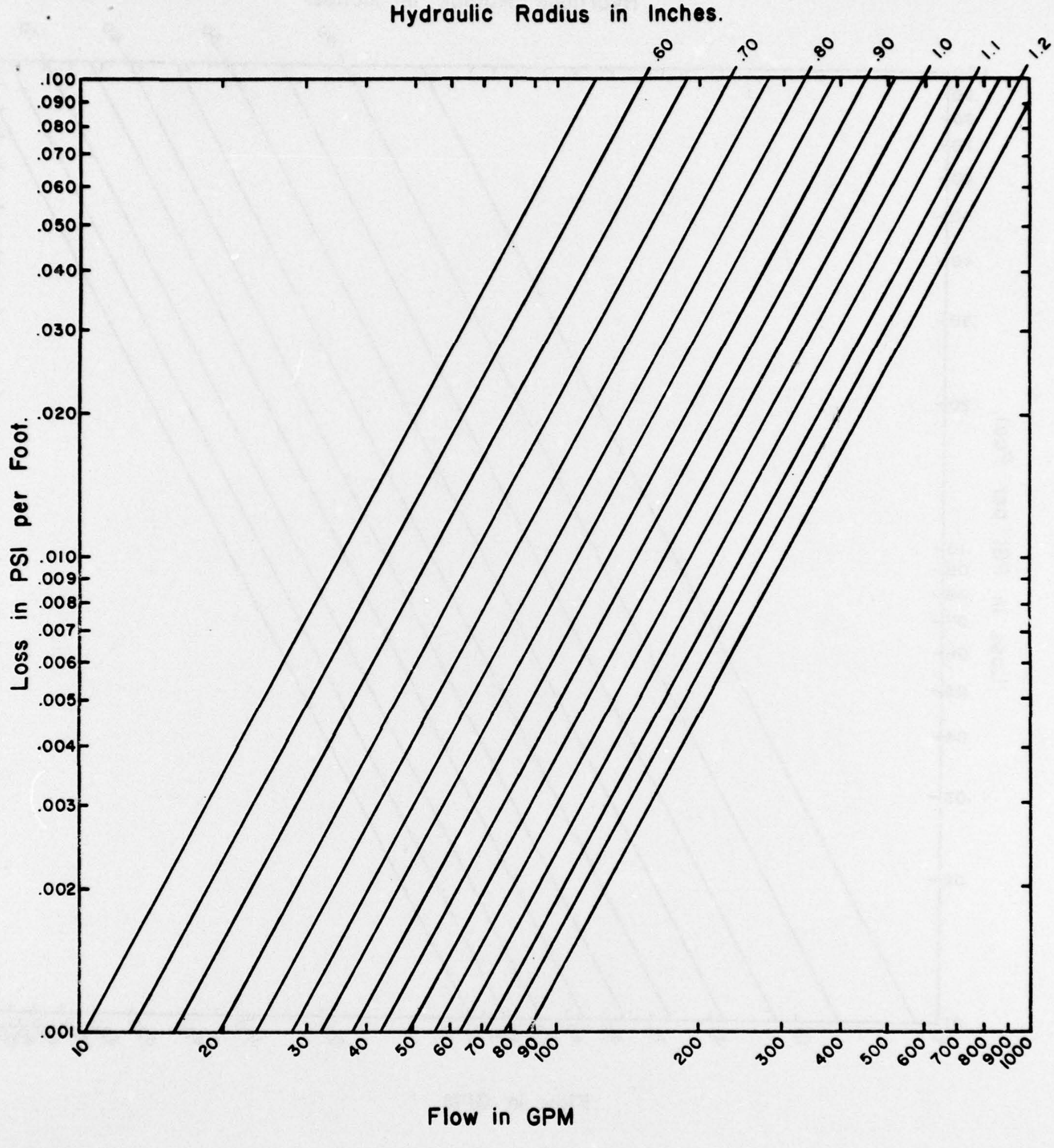


Figure. No. 21. Friction Loss in Non-Circular Pipes
H&W C=120
(Hydraulic Radius = Area ÷ Perimeter)

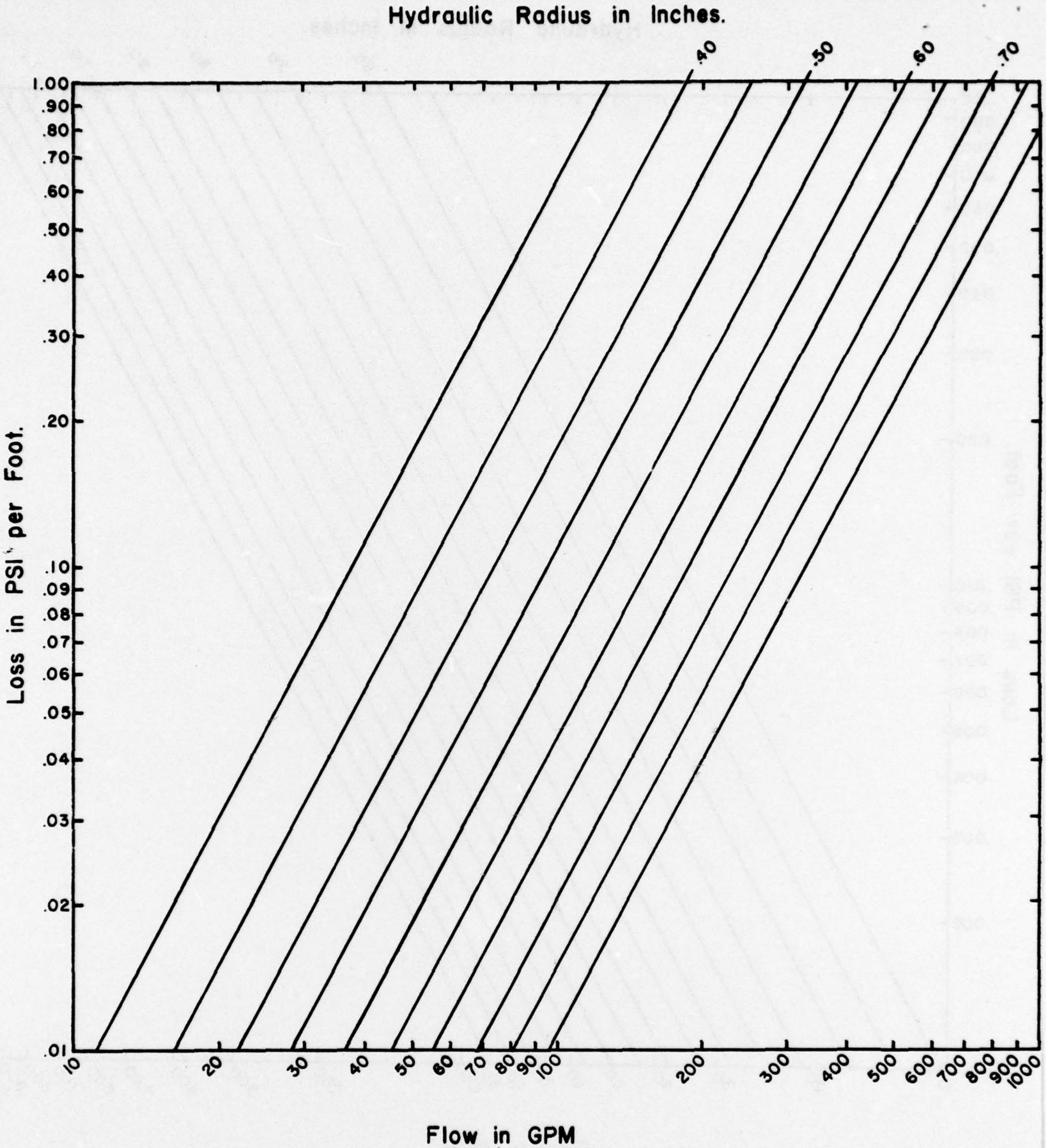


Figure. No. 22. Friction Loss in Non-Circular Pipes
H&W C=120
(Hydraulic Radius = Area ÷ Perimeter)

APPENDIX B

DATA SUPPLIED BY GRINNELL FIRE PROTECTION SYSTEMS COMPANY, INC.

1467 ELMWOOD AVENUE
CRANSTON, R. I. 02910
TEL: (401) 781-3800
TELEX: 92 7526

November 18, 1975

Factory Mutual Research
1151 Boston- Providence Turnpike
Norwood, MA 02062

Attention: Mr. L. M. Krasner
Senior Research Scientist

Subject: Naval Facility Contract
N00025-74-C-0023

GRINNELL FIRE PROTECTION SYSTEMS COMPANY, INC.

Gentlemen:

Enclosed is one print each of our drawings No. 1 through 5 showing the proposed rack protection for a standard rack system and Factory Mutual's layout using the 4-inch tubular steel columns on the racks to supply the sprinkler heads.

Both rack systems consisting of 4,553 Grinnell Q-16 sprinklers are supplied by one sprinkler riser with an alarm valve and are hydraulically calculated to deliver 30 psi through the most remote sprinkler on top line with 14 sprinklers operating, 7 each on the top two levels. Pressure available at the base of the riser would be 100 psi with approximately 480 gallons flowing. The standard rack system would require a 6-inch alarm valve and riser and the Factory Mutual system would require a 4-inch alarm valve and riser.

We have estimated the Factory Mutual system would cost $207,181.00 to install, less overhead and profit, against $297,259.00 for the standard rack system or approximately 30% less.

We are attaching copies of work sheets showing the costs for each system, plus a summary sheet comparing the engineering, material and labor for each system. The engineering charges for each system would be the same, material for the Factory Mutual system would be approximately $88,669.00 or 26.9% more than the standard layout. **The Factory Mutual system would result in a labor savings of 48.6%.**

Not included in our cost comparison would be the price of 4553 1-inch couplings welded to the 4-inch tubular supports, 2275 4-inch steel plates with 2½-inch couplings welded to the top of the tubular supports of the racks and 2275 3/4-inch drain connections installed at the bottom of the tubular supports of the racks if required.

EXECUTIVE OFFICES
PROVIDENCE, R. I.

The price for the Factory Mutual layout was based on 3½-inch crossmains at the top of the racks cut five foot on center with a Victaulic coupling before each standard screwed tee. If we could substitute a 20-foot length of 4-inch thin wall pipe with four 2½-inch grooved brancholet outlets welded five foot on center as shown on our alternate layout of attached sketch "A", we could save approximately $4,200.00 on the material price over the 5-foot pieces of 3½-inch main with a grooved coupling.

To use the 20-foot length of 4-inch pipe with the four 2½-inch outlets welded five foot on center, the 4-inch tubular supports on the racks would have to be spaced exactly five-foot on center.

We are forwarding under separate cover sepias of our five drawings No. 1 through 5 showing the rack layouts.

If you have any questions, please call.

Very truly yours,

GRINNELL FIRE PROTECTION
SYSTEMS COMPANY, INC.

A. J. Girard
District Manager

AJG/dab

Enclosures

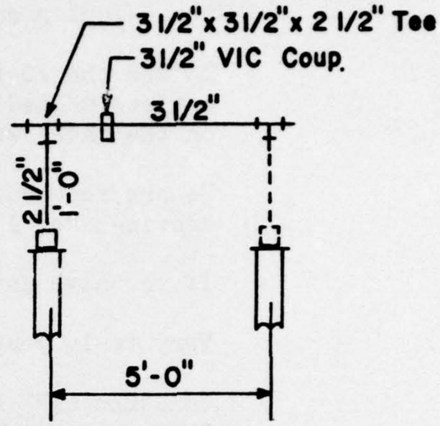
SKETCH "A"

FM LAYOUT

Material Cost

1 - 3 1/2" Tee	5.76
1 - 3 1/2" Vic Coup	4.85
5 ft 3 1/2" Pipe @ 1.8¢ per ft	9.18
2 ea. Cuts	1.04
2 ea. Thds.	1.02
2 ea. Grooves	5.28
1 - 2 1/2 x 1-0 Nip	2.69
Total	29.82

For 5'-0" Segment
2275 Conn's @ 29.82 = $67,840.50



ALTERNATE LAYOUT

Material Cost

20 ft of 4" Thinwall @ 1.66		33.20
4 - 2 1/2" Grvd Brancholet	6.58	26.32
1 - 4" Vic Coup		4.85
2 - 4" Grooves		5.28
1 - Cut		.52
Shop Operation (Welding)		19.48
4 - 2 1/2" Groove Coup.		11.40
4 - 2 1/2" x 1-0 Nip @ 2.69		10.76
	Total	111.95

For 3 Segments, 4 Conn's.
Cost per Conn. 2795

2275 Conn's @ 27.95 = $63,586.25
Savings of 4,254.25

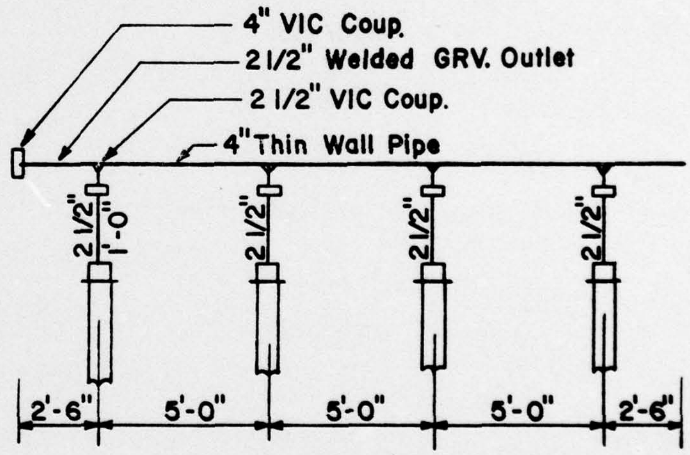


FIGURE 23

MATERIAL COSTS OF ALTERNATIVE LAYOUTS

TABLE 4

RACK SYSTEM COST COMPARISON

	FM LAYOUT	STANDARD LAYOUT	FM LAYOUT VS. STANDARD Over	%	Under	%
Engineering	$ 3,600	$ 3,600	-		-	
Material	88,669	69,841	$18,828	26.9		
Labor	114,912	223,818			$108,906	48.6
Total	207,181	297,259			90,078	30

Actual Estimated Cost Less Overhead & Profit

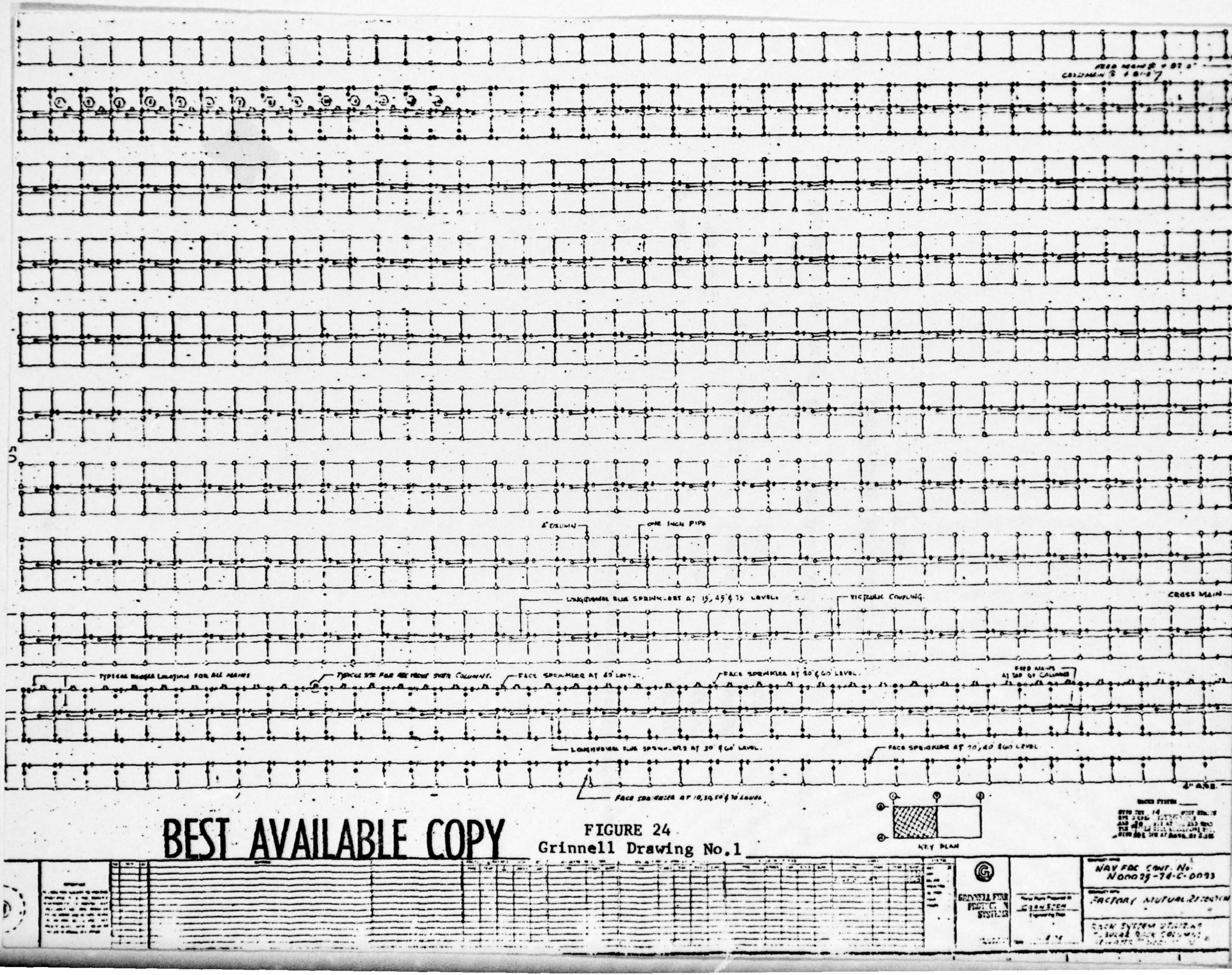


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FIGURE 24
Grinnell Drawing No.1

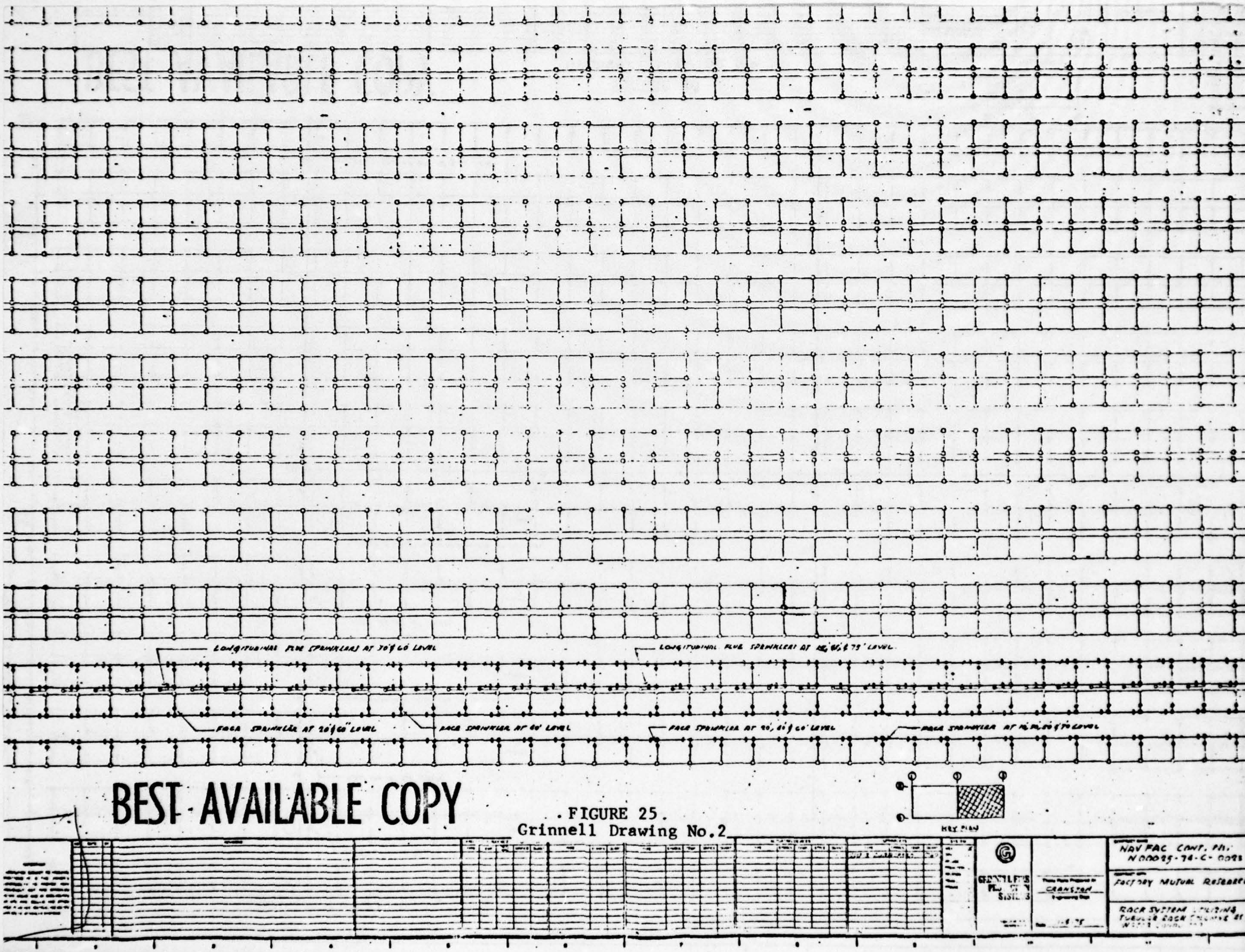

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FIGURE 25.
Grinnell Drawing No.2

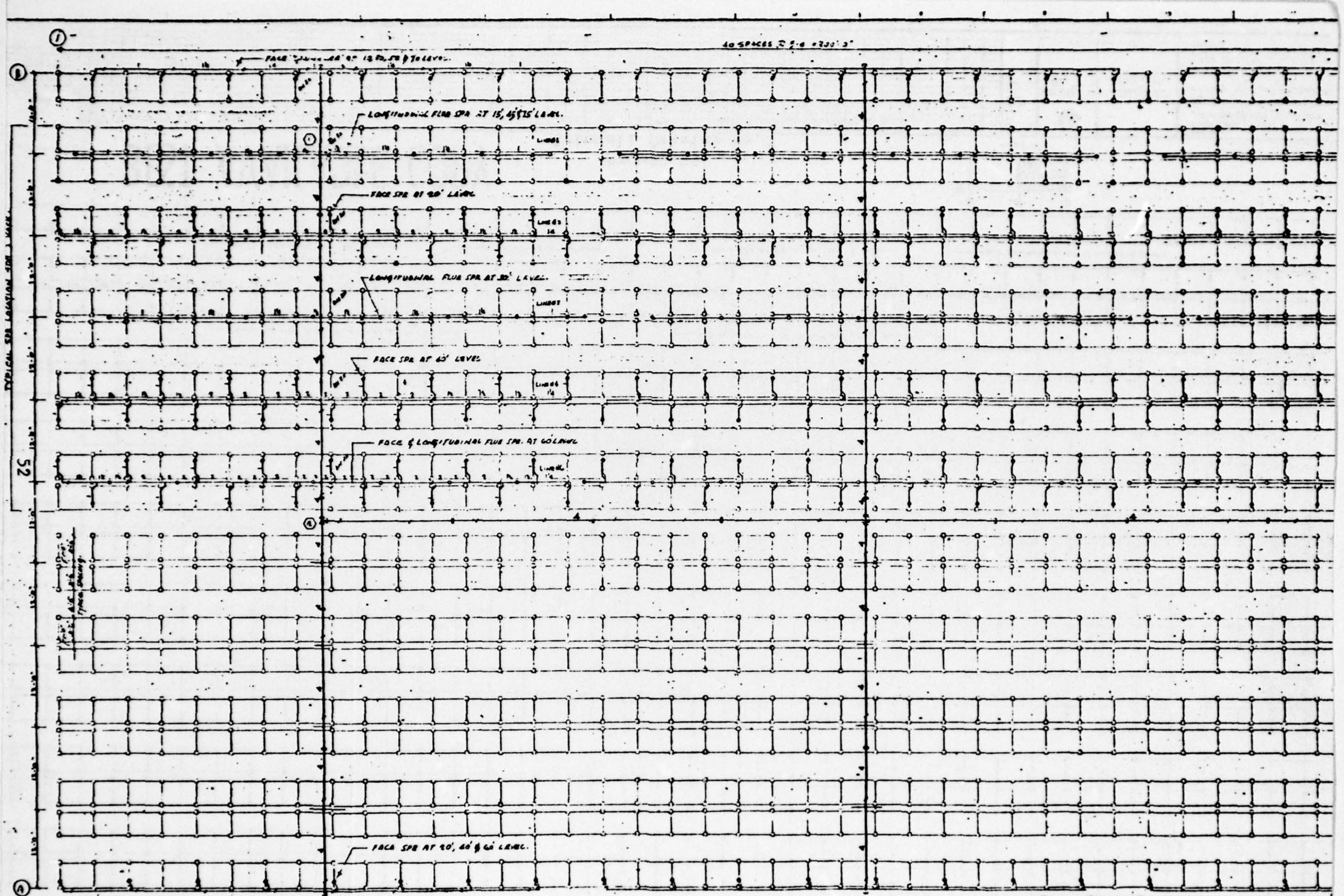

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FIGURE 26
Grinnell Drawing No.3

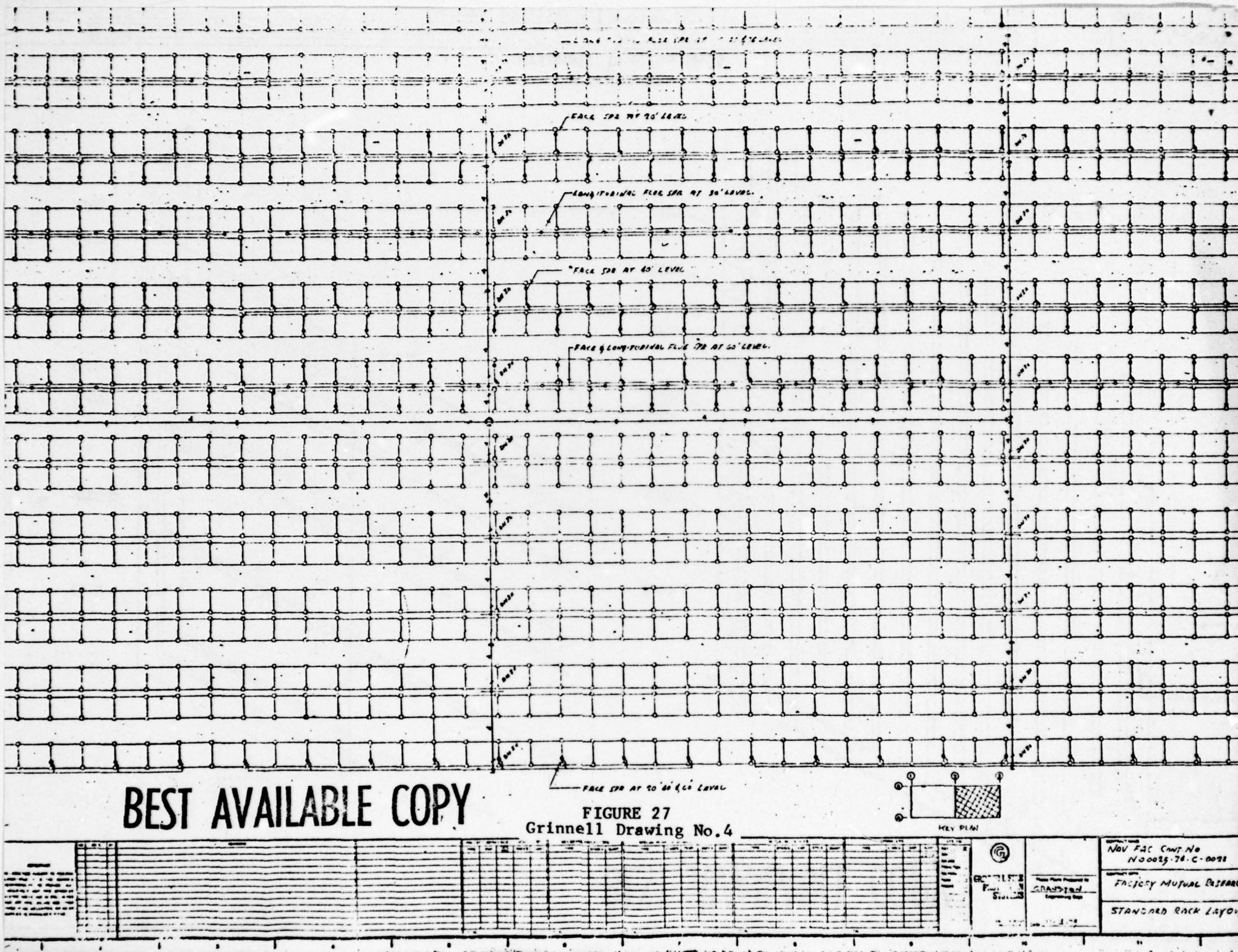

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FIGURE 27
Grinnell Drawing No.4

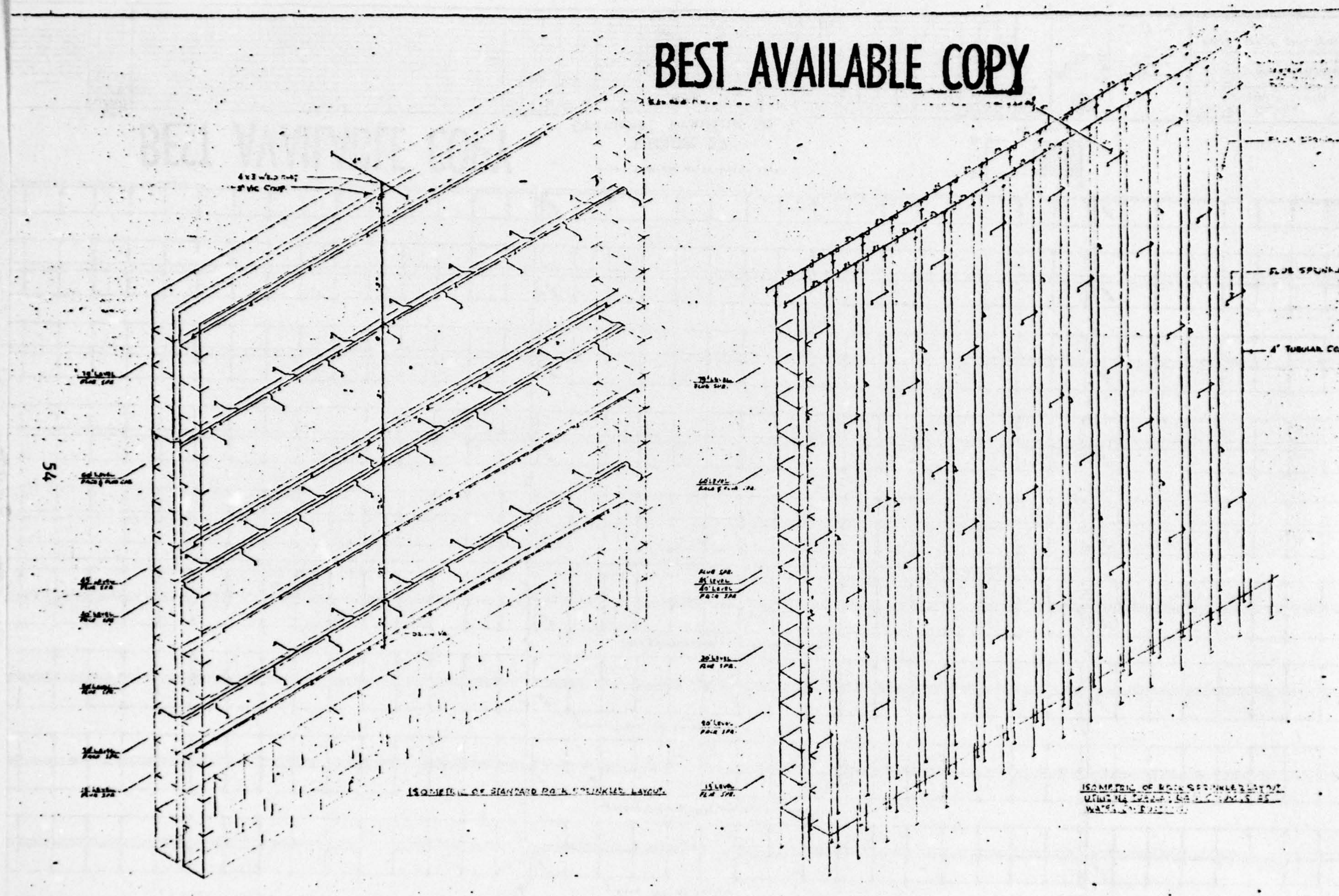

FIGURE 28
Grinnell Drawing No.5