EVALUATION ON CABLE TRAY SYSTEM DAMPING FOR WNP-1, WASHINGTON PUBLIC POWER SUPPLY SYSTEM

Prepared by:

L. J. Pons

S. Y. Tuann

Approved by:

for W. H. White
Chief Civil Engineer

Bechtel Power Corporation

San Francisco, California

August, 1985

August 27, 1985

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1.0 Purpose

The purpose of this evaluation is to substantiate the use of higher damping than previously used in the seismic design of the cable tray system at WNP-1. The primary justification for the higher damping is provided by the results of the Bechtel raceway seismic test program (Reference 1). Use of such higher damping is more realistic and will enable reduction of structural response, thus allowing optimization of cable tray system design and installation.

2.0 Recommendation

Based on Bechtel's review of WNP-1 cable tray design and installations and comparison with the systems of the Bechtel raceway test program, the damping curve of Figure 1 is recommended for design use at WNP-1. Bechtel has concluded that it would be conservative to use this design damping curve for the WNP-1 cable tray system. A detailed justification for the recommended damping curve (Figure 1) is provided in this evaluation.

Figure 1 additionally recommends damping for trapeze type conduit supports.

Structural responses (e.g., bending and shear stresses, etc.) and fatigue capacities are to be evaluated for the Safe Shutdown Earthquake (SSE) for both cable tray and applicable conduit support systems. Connection fatigue capacities only are to be evaluated for the Operating Basis Earthquake (OBE).

The recommended maximum damping for cable trays is 20%, compared to the presently used damping of 4% and 7%, for OBE and SSE, respectively. The recommended damping for bolted trapeze-type conduit supports is 7%, compared to the presently used damping of 2% and 3%, for OBE and SSE, respectively.

3.0 Introduction

In the past, raceway systems at several power installations would have been predicted to be inadequate for survival, if analyzed by previous criteria which required use of damping values less than those presently recommended. However, such systems have in fact survived actual earthquakes with only minor damage. This prompted Bechtel to undertake a test program to better understand raceway system dynamics. It was hoped that the test results could be used to improve the traditionally conservative design approach. The initial phases of the test program were centered around cable tray raceway systems. The test program and results are described in Reference 1. One of the conclusions is that the tested systems have an equivalent viscous damping much higher than the 7% of critical damping for bolted structures allowed by NRC Regulatory Guide 1.61 (Reference 2) for SSE loading. As detailed in the test report, Reference 1, numerous cable tray systems have been tested, and the effects of a broad range of parameters on system damping have been investigated. Threaded-rod hangers, rigidly mounted supports, and strut hangers with various degrees of lateral restraint, as well as various cable fill amounts and numerous system configurations have been tested. Results of these tests have demonstrated that the damping of tray systems is influenced most significantly by the amount of cable fill in the tray and by the input motion level.

For systems such as cable tray raceways which consist of structural as well as non-structural elements such as cables, the effects of the various mechanisms which can dissipate system energy are typically lumped together in a single factor known as effective viscous damping. As this apparent damping is dependent on many factors in a non-linear manner, it is commonly quantified by means of dynamic tests which include the variation of known energy dissipating mechanisms. In cable tray systems, some of these mechanisms are friction between the cables themselves and between the cables and the tray through relative movement, friction and slip of the support bolted connections, hysteresis of materials, and radiation of energy into the supporting structure.

As a dynamic system the cable tray raceways differ from ordinary load bearing bolted or welded structures in that the bulk of the system mass is not integral with the stiffness of the system. As a result, under dynamic loading, a significant amount of excitation energy is used to produce relative motion between cables and tray and among the cables themselves. Therefore, the predominant energy dissipating mechanism is relative motion of cables in the tray. This energy dissipation behavior has been observed throughout the cable tray system tests.

The trend of varying damping with cable fill and input motion level was clearly identified in the test. Damping of empty tray systems was observed similar to that of a bolted structure. Increased cable fill and excitation level increased the damping.

As the amount of relative cable motion is a function of the input motion levels of acceleration of a raceway system, damping tends to increase with increasing input motion. Increased support rigidity did not significantly impact system damping. It was observed that unbraced, long strut hanger systems behave similarly to flexible threaded-rod hanger systems, where the cables tend to move in phase with the tray; thus somewhat less damping occurs than with the stiffer system responding to the same level of excitation. This difference can be attributed to the greater tray deformation that is induced by stiffened and restrained supports which in turn results in more energy being dissipated by the tray and its contents. Thus higher system damping occurs.

The damping values calculated based on the recorded dynamic input and response were plotted against input level in Figure 7. This plot clearly demonstrates that the tested cable tray systems when subjected to an input "g" greater than 0.1 have an equivalent viscous damping much higher than that permitted by Regulatory Guide 1.61 for bolted structures. Results from tests of many support types (ranging from very flexible to rigid) and configurations (relative to transverse and longitudinal bracing, hanger length, number of tiers, and anchor and connection types) were included in

the plotted data. In the interest of providing a generic design damping curve for practical amounts of cable fill but with no regard to support type, the conservative lower bound of the test data, represented as a bilinear curve is shown in Figure 1.

The variability of test data in Figure 7 is indicative of the differences in the dynamic characteristics of tray support systems and the variability of test parameters included in the test program. When the data for a particular support system are isolated for a damping trend study, the damping trend for that particular support system with input acceleration magnitude becomes clear. This is evident from Figures 8, 9 and 10. A detailed discussion of the equivalent system damping as a function of support system cable fill and input level is included in the test report, Reference 1.

Moreover, dynamic analyses to simulate several tested raceway systems have confirmed that an assumption of very high viscous damping is necessary to produce responses similar to those observed during actual testing.

Vertical cable tray systems were also evaluated as part of the cable tray seismic test program. Based on the test results and, because the same damping mechanisms exist for vertical as well as horizontal trays, it is concluded that the higher damping is equally applicable to vertical cable tray. In general, and as is the case at WNP-1, the linear footage of horizontal tray is substantially larger than that of vertical tray.

Figure 1 shows that for input levels above 0.1g, 7% damping exists for bolted trapeze-type conduit supports. The 7% damping has been verified by the test program which shows the damping is consistent with Regulatory Guide 1.61 for bolted structures. The damping value is not dependent on the amount of cable fill in the conduit as it is with cable tray; this is because the primary damping mechanism appears to be bolt and connection slippage and not cable friction.

3.1 Test Input Loading

In order to simulate biaxial seismic motion, the cable tray test input loading was applied at a 45° angle, providing simultaneous excitation in either the vertical plus longitudinal or the vertical plus lateral directions. In choosing the 45° relationship (i.e., horizontal equals vertical) the floor response spectra of many containments and auxiliary buildings were reviewed and the equality of horizontal and vertical motion was deemed most appropriate. Moreover, in the case of cable tray systems, dominant modes are typically either vertical or horizontal, and are therefore adequately excited by vector biaxial motion. Also, vertical and horizontal modes are typically quite distinct, and respond independently in spite of dependent input motion. Distinct, widely spaced modes of vibration with little cross coupling were observed during testing, thus confirming the validity of design damping data obtained using vector biaxial input.

Preliminary results of recent tests using pseudo-triaxial input motion substantiate the results obtained in the previous biaxial tests. The results of biaxial tests are compared with the results of pseudo-triaxial tests (on similar tray support systems) in Figure 15. The data, while limited, indicates little change in system damping when three axes rather than two are excited simultaneously. There is some indication that the use of pseudo-triaxial input motion tends to equalize the damping in the longitudinal and transverse directions, although any shift is relatively small. The damping trends exhibited by the biaxial testing would also be exhibited using pseudo-triaxial input.

4.0 System Comparison

This section compares WNP-1 cable tray systems (Figures 4, 5 and 6) to the systems tested as part of the Bechtel cable tray testing

program. Appendix "A" summarizes this comparison and documents the similarities between the two systems.

The tested support systems were constructed using standard cold-formed struts and standard bolted fittings from a variety of manufacturers. Cable trays and fittings for the tests were provided by several manufacturers, including P. W. Industries and Husky-Burndy which are the suppliers of cable tray used at WNP-1. Tests included trapeze supports of varying height and transverse and longitudinal bracing configurations. Figures 2 and 3 show a typical set-up of tested systems. Cable loading ranged from 0 to 50 pounds per foot.

The fundamental frequencies of the tested support configurations were in two ranges: The more flexible support systems had system fundamental frequencies of 2 to 6 cycles per second (CPS); the more rigid support systems had a range of 9 to 25 CPS. The latter frequency range resulted primarily from tray variations, as the supports themselves were rigid.

The wide variety of the tray types and support configurations included in the test program simulated actual field installed conditions. A large number of variables was investigated, including:

- Types and manufacturers of Trays
- Type and Size of Tray Supports
- Location of Tray Splices
- Number of Tray Tiers
- Configuration of Support Systems
- Type and Spacing of Transverse and Longitudinal Bracing
- Weight of Cables
- Cable Ties

Extensive dynamic testing of the effects of these and other variables has produced voluminous raw data, which have been summarized in the test report. In view of the scope of the test

program, it is concluded that the tests are representative of a variety of actual field conditions, and that the results are applicable to the design of comparable tray support systems, such as WNP-1's.

The testing program clearly demonstrated that a significant portion of the system damping was a product of cable motion and the resulting friction between cables and between cables and trays. Therefore, in order to assess the compatibility of the WNP-1 system and the tested system, the frequency and general characteristics of the WNP-1 system were studied to determine whether they fall within the bounds of the test program, thereby providing assurance that the cable motion necessary to produce the predicted damping will occur.

Appendix A compares the significant characteristics of the tested cable tray system to those of the WNP-1 cable tray system. Based on the fact that the WNP-1 cable tray system is sufficiently similar in all significant characteristics (including cable fill and input motion level, trays and support configuration and details) to the tested cable tray systems, it is concluded that the results (i.e., the high energy dissipation mechanism) of the Bechtel cable tray testing program are directly applicable to WNP-1.

Extensive use of overhead auxiliary steel is made at WNP-1 to bridge the space between the tray hanger steel and the building structural steel. Damping used for the auxiliary steel should be in accordance with Regulatory Guide 1.61. The recommended higher damping is applicable only for the hanger steel and cable tray.

4.1 Support System Frequency Comparison

Typically, WNP-1 cable tray system frequencies are in the rigid range of the tested systems. However, the test results indicate that the contribution of the tray support itself to the system damping is not as significant as the contribution of the cable.

The tested support systems which are most similar to the WNP-1 system are the trapeze supports with transverse bracing at every support (Type A), and the rigid supports, i.e., where the tray is directly attached to the shake table. The typical WNP-1 support fundamental frequencies actually fall somewhere between the typical frequencies of the Type A and the rigid test supports. When the test data for the Type A and rigid support systems are used independently (Figure 11), it becomes apparent that the damping trend exhibited by these support systems is well in excess of the 20% damping recommended for design use.

The test data for the Type A system (Figure 12) and the rigid system (Figures 13 and 14) also demonstrate that the data for each particular type of test system is consistent. By isolating each of the system types, the apparent scatter of the data is minimized, and the damping trends are more clearly defined.

5.0 Future Considerations to Ensure Recommended Damping

This section discusses areas where particular care should be exercised in design, construction approach, or material selection to ensure that the use of the higher damping remains valid.

5.1 Fireproofing

Fireproofing sprayed directly on the cables should not be used because cable motion, which is the principal mechanism for generating damping, would be inhibited. Other types of fireproofing are acceptable provided that effects of the additional dead load are considered.

5.2 Cable Tray Covers

If used, approximately 1/2" clearance should be maintained between cables and the tray cover. Smaller clearances may not allow cable movement and, thus, inhibit damping.

5.3 Tie Spacing

Tie spacing of not less than 6 ft. (nominal) is recommended for horizontal tray runs and not less than 4 ft. (nominal) for vertical tray runs. From a damping perspective, the fewer ties there are, the more the potential for damping since the cables are allowed to freely move. Tests indicate that ties of significantly smaller spacing than stated above may affect damping.

5.4 Other Commodities

In general, the cable tray supports can be used to support other commodities (e.g., conduits, tubing, etc.) while still maintaining essentially the same damping value allowed for the cable tray system alone. The amount of non-cable tray mass that a tray hanger can support should be limited to a justifiable percentage of the total mass, e.g., 20% of the total mass, as justified by analysis.

5.5 Damping for Future Systems

The damping recommendations provided herein are made specifically for the existing WNP-1 design and installations. However, the same damping values can be used for future, more flexible designs (i.e., systems with less than the existing bracing) because the damping mechanisms remain the same. Documentation is available to justify high damping for cable tray systems of other frequencies.

6.0 Conclusion

The WNP-1 cable tray system has been reviewed by Bechtel. Based on this review, Bechtel has determined that the high damping observed during the cable tray test program is applicable to WNP-1.

This recommendation is based on a plant walkdown, review of detail installation and layout drawings, design criteria, calculations and response spectra, and technical discussions with WNP-1 Architect/Engineer personnel, United Engineers and Constructors.

The tested configurations included a wide variety of tray types, support types, connection details, cable loadings, and bracing schemes. Appendix A documents the similarities between the tested cable tray system and the WNP-1 installed system. All characteristics essential for high damping are present for the WNP-1 cable tray system. The tested trays and hanger configurations are representative of those at WNP-1.

Damping values from the tested cable tray systems which are most representative of the WNP-1 trays are shown in Figure 11. The bilinear curve represents a conservative bound of these damping values. Thus, the damping values recommended for use at WNP-1 (Figure 1) are conservative in that virtually all measured damping was consistently and significantly higher than the recommended curve. As a result, use of the lower-bound damping values is conservative since the actual structural responses will be significantly lower than the calculated responses.

7.0 References

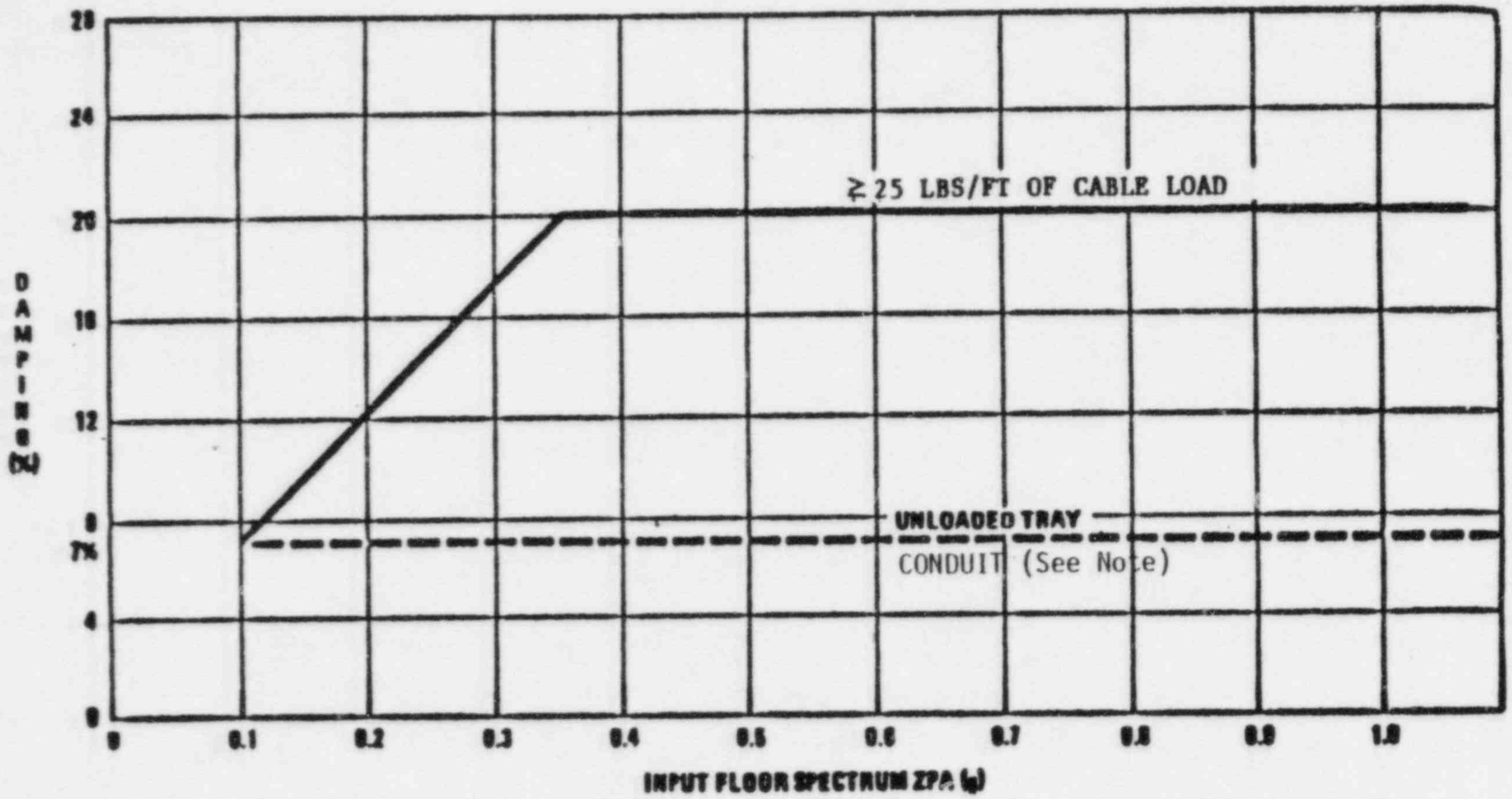
1. "Cable Tray and Conduit Raceway Seismic Test Program - Release 4 (Final)", Test Report # 1053-21.1-4, Vol. 1 & 2, December 15, 1978, Vol. 3, May, 1980, Vol. 4, March, 1981, ANCO Engineers, Inc.(Forwarded to NRC January 21, 1980 via letter from R. J. Kosiba of Bechtel Power Corporation to Dr. F. Schauer of Structural Engineering Branch, NRC).

2. U. S. N.R.C. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October 1973.

Parameter	Test Program	WNP-1	Comments/Discussion
1.0 Parameters essential for Damping per Figure 1			
1.1 Cable Load	Cable Load 0-50#/ft	Design Load = 50#/ft (Local section may exceed 50#/ft)	Min. load to achieve 20% damping is 25#/ft. cable load. 100% test load is 50#/ft for 24" tray.
1.2 Floor Acceleration	Various Accelerations (0.1g to 2.2g)	Most elevations have ZPA $\geq$ .35g	For locations that do not have .35g ZPA, interpolate curve to determine damping. If ZPA $\geq$ .35g, then 20% damping exists for tray loaded per 1.1 above, regardless of frequency or acceleration.
1.3 Hanger Frequency	All ranges tested (Approx. 2-25 cps)	Rigid (Generally above 10 cps)	In general, stiffer supports tend to promote higher damping.
2.0 Hanger Comparison			
2.1 Support Type	Trapeze (Majority)	Trapeze (Majority)	
2.2 Trays per Horizontal Rung	One	One	
2.3 Tiers	5 (Max)	7 (Max) (to 9 in limited locations)	Number of tiers has no significant damping impact since damping mechanisms are unchanged.
2.4 Support Spacing	8' Max	10' (Max) (Typ as-built spacing is less)	Support spacing variations in this range have no significant impact on damping, since damping mechanisms are unchanged.
2.5 Max Dead Load per Support	2200 lbs (Max.)	3800 lbs (Max.) (to 4900 in ltd. locations)	Magnitude of the dead load on support has no significant effect on the damping mechanism.
2.6 Vertical Member	B-22A (P1001)	P1004A (for hanger; W6 for	

Parameter	Test Program	WNP-1	Comments/Discussion
		overhead structural steel)	
2.7 Horizontal Member	P1001, 3' Max (B-22A)	P1001, 3' Max	
2.8 Transverse Bracing	P1001, Various Configurations (B-22A)	P1004A, Ea. Hanger	Test bracing configurations ranged from ea. hanger to no bracing. Amount of bracing does not affect damping mechanism.
2.9 Longitudinal Brace	P1001, Various Configurations (B-22A)	Structural Channel Every 4th Bay	Test bracing configurations ranged from every other hanger to no bracing. Amount of bracing does not affect damping mechanism.
3.0 <u>Connection Comparison</u>			
3.1 Overhead to Vertical Member	Double 4-hole or double 4-hole gussetted	Double 5-hole Gussetted (T-17) (Figure 10)	Differences between WNP-1 and test configuration have no effect on damping since the damping mechanisms remain the same. (applies to 3.1–3.4)
3.2 Hor. member to Vertical Member	Double 4-hole	Single gussetted; 5-hole at bottom (T-17), others 4-hole (P-1331 & P-1332)	
3.3 Transverse Bracing	Unistrut 2-hole Angular fittings double side	Custom-made half-moon bracket for various angles	
3.4 Longitudinal Bracing	Unistrut 3-hole flat plate	Tray side rail bolted to Structural C6 Channel	

Parameter	Test Program	WNP-1	Comments/Discussion
4.0 <u>Tray</u> <u>Comparison</u>			
4.1 Manufacturer	P-W, MPC, B-Line, H-B, ladder & trough	P-W, H-B, ladder type	
4.2 Size	24"	6" - 30" (24" Predominant)	Recommended damping for other than 24" tray is applicable provided the amount of fill is proportionately the same as for 24" tray.
4.3 Cable Tray Fill	0 - 100% by weight (50#/ft = 100%)	0 - 100% by weight (50#/ft = 100%) (Local sections may exceed 50#/ft)	
4.4 Tray Holddown	Friction Holddown	Friction Holddown	Square bent plate with one hole
4.5 Tray C. to C.	1' - 4"	1' - 4"	
4.6 Splice	Random location- as supplied by tray supplier	- same -	Splice type and location has no impact on damping values.
5.0 Cable Ties	5'-0" Vertical 2'-0" Horizontal - or greater (including no ties)	Not less than 4' Vertical (Nom.) Not less than 6' - 0" Horizontal(Nom)	See Sec. 5.3 for discussion
7.0 Cable size	Mixture of cable sizes	- same -	



DAMPING AS A FUNCTION OF INPUT ZPA

Fig. 1 Recommended Damping Curve for WNP-1

Note: 7% damping is applicable to bolted trapeze conduit hangers only

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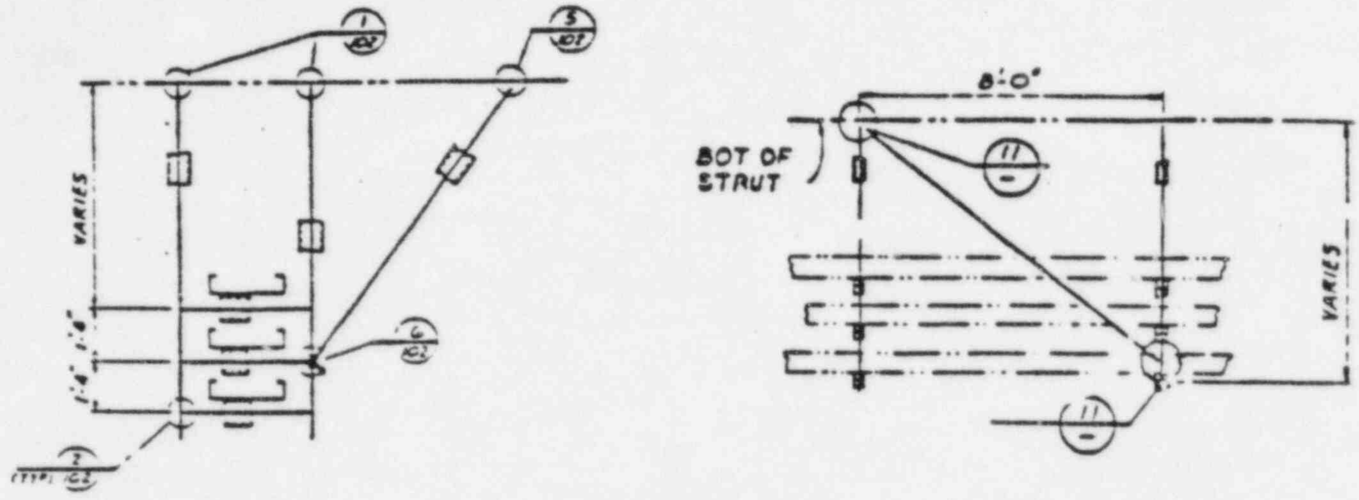
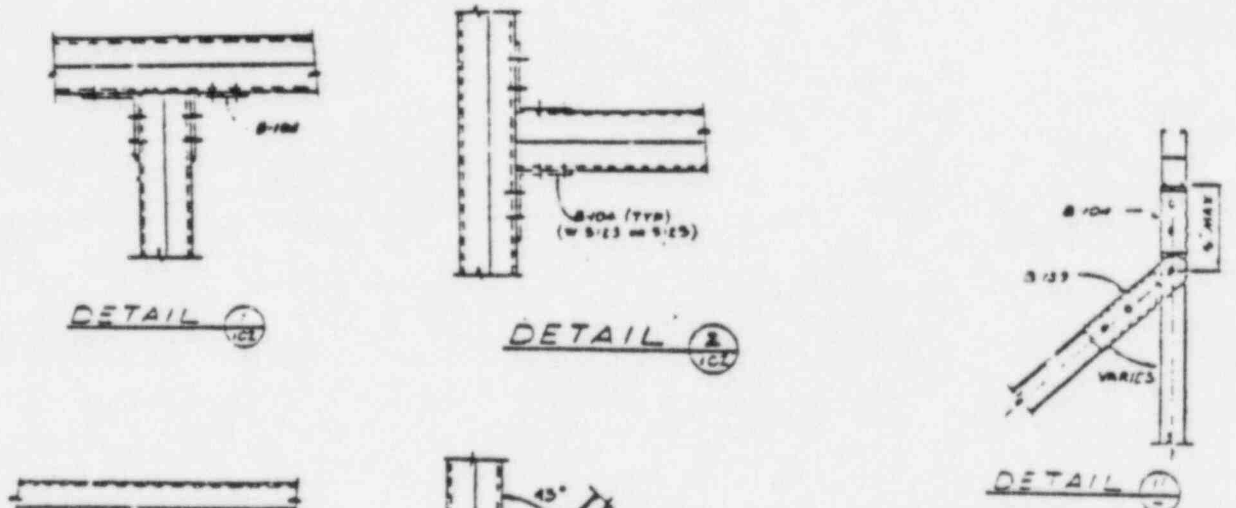
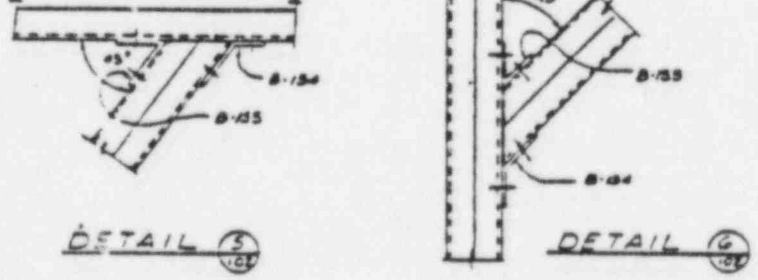


HANGER & TRANSVERSE, LONGITUDINAL BRACES

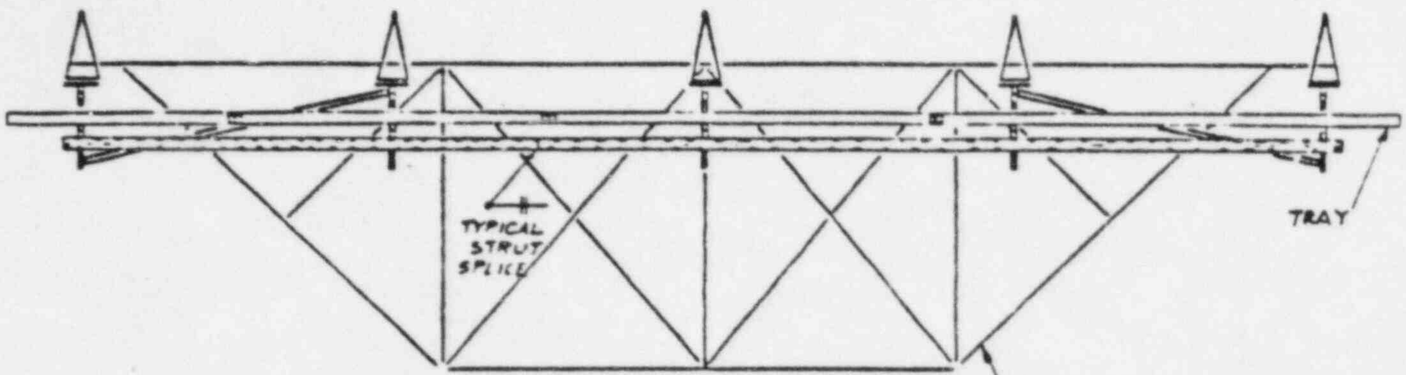




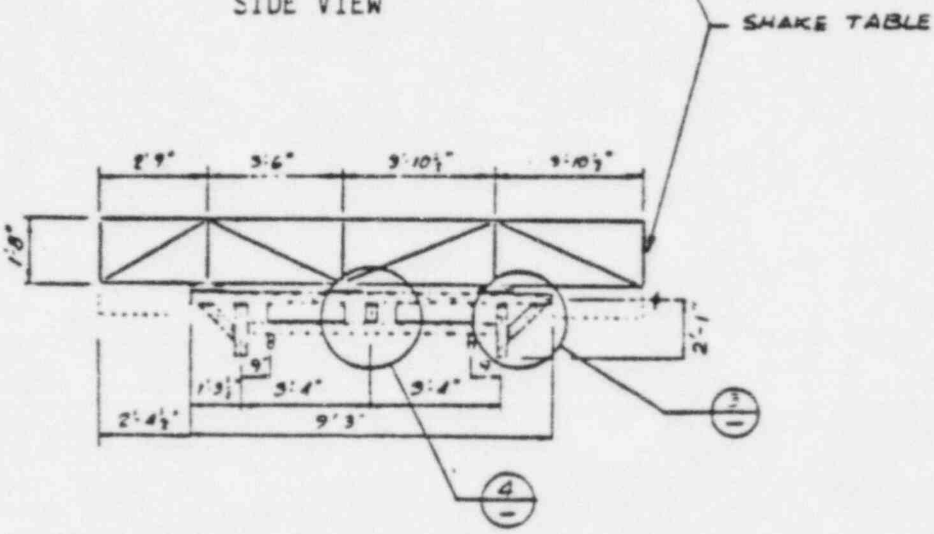
Note: Framing members are strut-type shapes such as B-Line B-22a or Unistrut P-1001

ANCHOR & CONNECTION DETAILS

Fig. 2 TYPICAL STRUT HANGER SUPPORT OF TEST PROGRAM

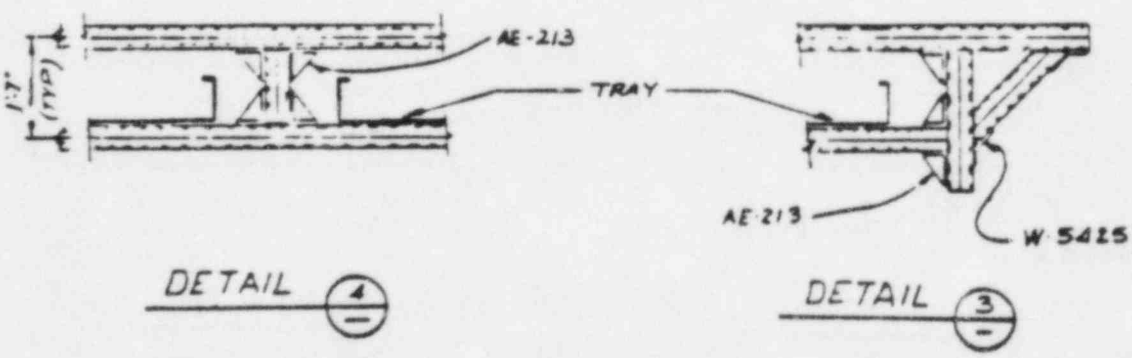


SIDE VIEW



END VIEW

NOTE: FITTING NOS. ARE FOR
STRUT-TYPE CONNECTION FITTINGS
SUCH AS B-LINE OR UNISTRUT



DETAILS OF RIGID SUPPORT

Fig. 3 TEST SET-UP FOR RIGIDLY SUPPORTED TRAY SYSTEM

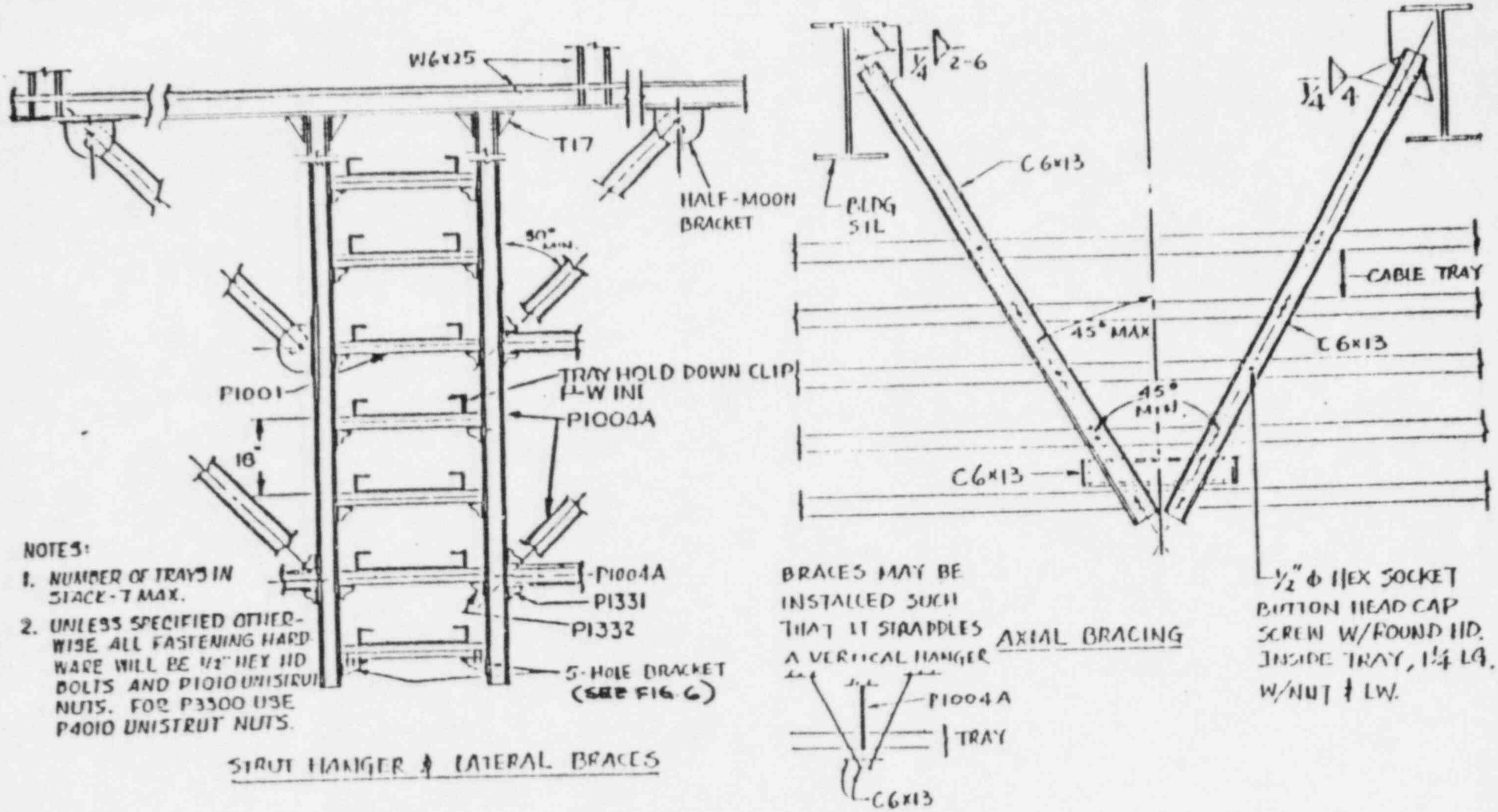


Figure 4 WNP-1 TYPICAL EXISTING STRUT HANGER SUPPORT TYPE

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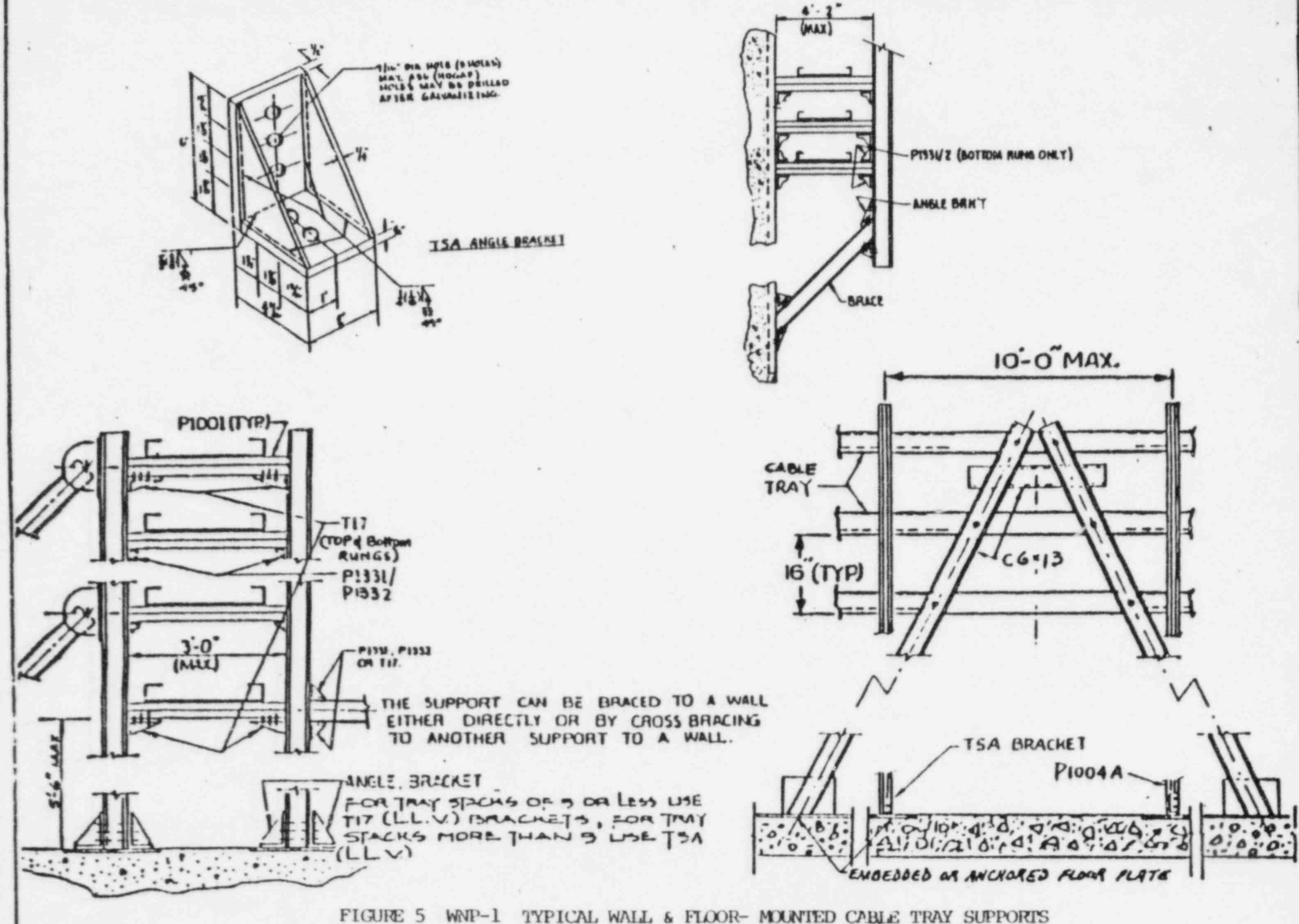
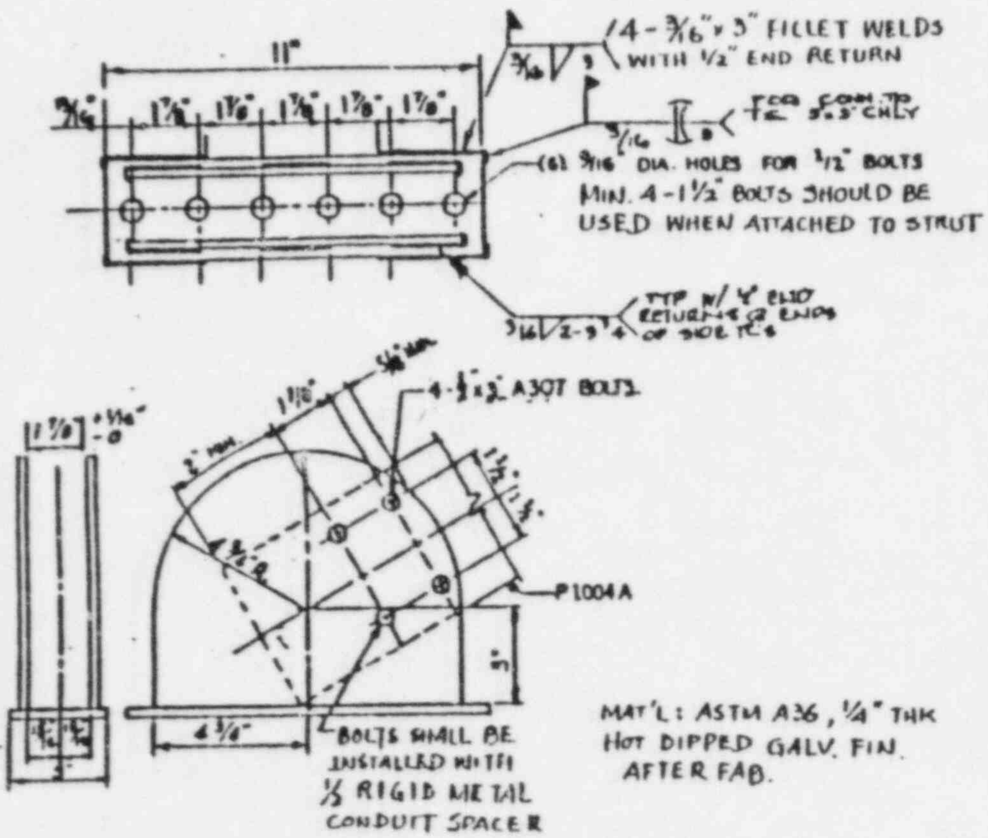
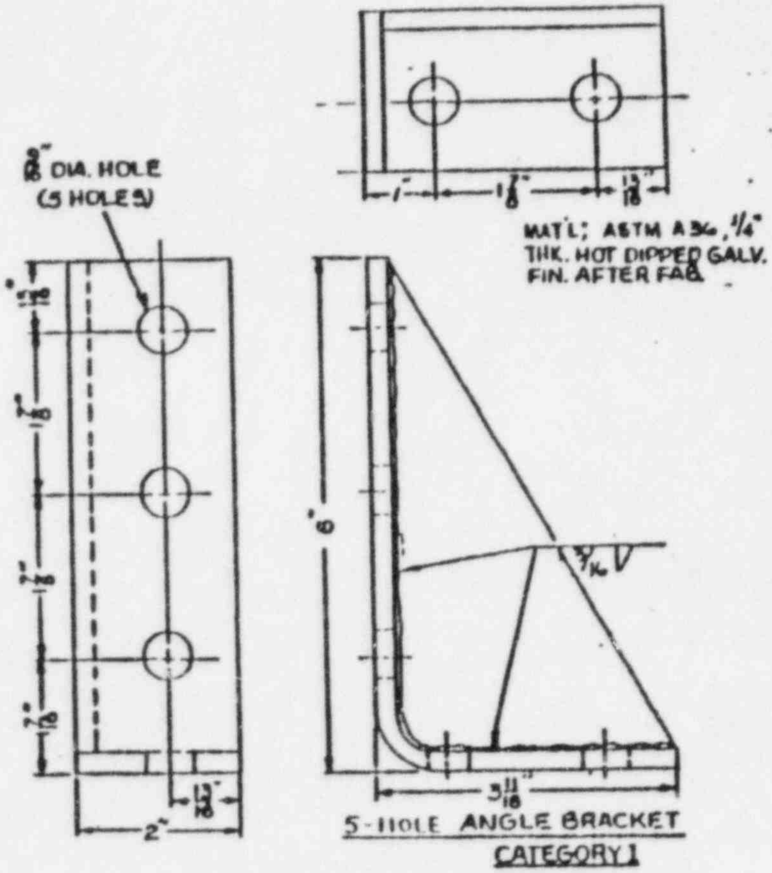


FIGURE 5 WNP-1 TYPICAL WALL & FLOOR- MOUNTED CABLE TRAY SUPPORTS



HALF-MOON BRACKET



T17 BRACKET

Fig. 6 WNP-1 CUSTOM MADE BRACKETS

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