March 7, 2006

L-MT-06-013
10 CFR 50.90

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Monticello Nuclear Generating Plant
Docket 50-263
License No. DPR-22

License Amendment Request for Contingent Installation of a Temporary Spent Fuel Storage Rack

Pursuant to 10 CFR 50.90, the Nuclear Management Company, LLC (NMC) proposes to revise the Monticello Nuclear Generating Plant (MNGP) licensing basis to allow for installation of an additional temporary 8 x 8 (64 cell) high-density spent fuel storage rack in the spent fuel pool to maintain full core off-load capability. Approval of this license amendment request will temporarily increase the licensed spent fuel pool capacity from 2237 to 2301 fuel assemblies.

NMC is obtaining a Programmed and Remote (PaR) Systems Corporation 8 x 8 spent fuel storage rack from another nuclear power plant, to be installed if a situation were to arise requiring a full core off-load. NMC has performed a preliminary assessment of the PaR fuel rack criticality design information considering current General Electric fuel designs. Based on this assessment, the criticality performance of the PaR fuel rack is acceptable. To confirm this assessment, NMC will provide an MNGP specific criticality evaluation for the 8 x 8 PaR high-density spent fuel storage rack as a supplement.

Enclosure 1 provides the summary, present licensing basis, proposed changes, description of the spent fuel racks, technical analysis, and the no significant hazards and environmental considerations. Enclosure 2 provides a copy of Section 4.0, "Design Features," from the draft MNGP Improved Standard Technical Specifications (ITS) undergoing U.S. Nuclear Regulatory Commission review,[1] marked-up to reflect the proposed changes. Enclosure 3 provides pertinent sections of a PaR Systems Corporation report discussing the high-density spent fuel storage rack design.

NMC requests approval of the proposed amendment by January 19, 2007, since full core off-load capability will otherwise end during new fuel staging for the spring refueling outage. An implementation period of 60 days following approval is requested.

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1 On June 29, 2005, NMC requested to convert the MNGP to the ITS. Amendment issuance is expected in the spring of 2006. Processing of the proposed changes under ITS is discussed in Section 3.0 of Enclosure 1.

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Installation of the additional temporary PaR 8 x 8 high-density spent fuel storage rack will only occur in the event a full core off-load is required.

The MNGP Plant Operations Review Committee has reviewed this application. A copy of this submittal, including the No Significant Hazards Consideration determination, is being forwarded to our appointed state official pursuant to 10 CFR 50.91(b)(1).

This letter contains the following commitment:

- NMC will provide an MNGP specific criticality evaluation for the additional temporary PaR 8 x 8 high-density spent fuel storage rack by May 31, 2006.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 7, 2006.

John T. Conway

John T. Conway
Site Vice President, Monticello Nuclear Generating Plant
Nuclear Management Company, LLC

Enclosures (4)

cc: Administrator, Region III, USNRC
Project Manager, Monticello, USNRC
Resident Inspector, Monticello, USNRC
Minnesota Department of Commerce

LICENSEE'S EVALUATION OF PROPOSED CHANGE

ENCLOSURE 1

1.0 SUMMARY

Pursuant to 10 CFR 50.90, the Nuclear Management Company, LLC (NMC) proposes to revise the Monticello Nuclear Generating Plant (MNGP) licensing basis to allow for installation of an additional temporary 8 x 8 (64 cell) high-density spent fuel storage rack in the spent fuel pool (SFP) to maintain full core off-load (FCOL) capability. Approval of this License Amendment Request (LAR) will temporarily increase the licensed SFP capacity by 64 fuel assemblies, if required for a FCOL, from 2237 to 2301 fuel assemblies.

While not a regulatory requirement, NMC considers it prudent to maintain the ability to fully off-load the reactor core. NMC is obtaining a Programmed and Remote (PaR) Systems Corporation 8 x 8 high-density spent fuel storage rack from another nuclear power plant. Contingent installation of this temporary spent fuel storage rack is required from January 2007 (FCOL capability will end during fuel staging for the spring refueling outage) to approximately the fall of 2008, at which time the MNGP Independent Spent Fuel Storage Installation(1) (ISFSI) is expected to be operational. Prior to transfer of spent fuel assemblies to the ISFSI (assuming the PaR rack is installed), the PaR rack will be emptied, removed from the SFP, and subsequently a LAR submitted(2) to return the SFP capacity to the present licensed limit of 2237 fuel assemblies.

Movement of spent fuel from the SFP to the ISFSI cask storage location, after the ISFSI is operational, will ensure that long-term FCOL capability is maintained.

2.0 PRESENT LICENSING BASIS

In 1977, the MNGP Operating License(3) (OL) was modified to approve a license amendment to re-rack the SFP, replacing all but two of the original General Electric (GE) 2 x 10 - low-density design spent fuel racks with thirteen, 13 x 13 - high-density design spent fuel storage rack modules (Reference 1). This resulted in a total NRC approved licensed SFP capacity of 2237 spent fuel storage locations.(4) Only one of the two GE low-density racks was retained in

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1 Xcel Energy (the asset owner) and NMC are in the process of obtaining a Certificate of Need from the State of Minnesota which is required in Minnesota to construct an ISFSI.

2 A LAR will be submitted (if the PaR rack is not installed) once the ISFSI is operational and sufficient spent fuel assemblies transferred to re-establish FCOL capability.

3 Amendment No. 34 to the Provisional Operating License (dated April 14, 1978) increased capacity of the SFP from 740 to 2237 fuel assemblies. The MNGP current TS pre-date the standard TS and do not specify the licensed capacity of the SFP. Section B.2 of the OL was amended to reflect approval by referencing an August 17, 1977, Northern States Power letter dealing with fuel assembly storage capacity.

4 Two GE low-density racks with 40 cells and 13 high-density rack modules with 2197 cells.

the SFP, however, resulting in 2217 spent fuel storage locations. Of these, only 2209 are useable due to configuration limitations at 8 locations.

The SFP currently contains 1630 spent fuel assemblies. The MNGP reactor core holds 484 fuel assemblies. Prior to the 23rd refueling outage (RFO-23), NMC will begin staging replacement fuel assemblies (approximately 152) for Cycle 24. Staging of new fuel assemblies in the SFP will create a shortfall of storage locations in the SFP (assuming a FCOL is needed).

3.0 PROPOSED CHANGES

On June 29, 2005 (Reference 2), MNGP requested to convert to the Improved Standard Technical Specifications (ITS). Issuance of the license amendment approving the conversion is expected in the spring of 2006, with implementation scheduled for the fall. In consideration that the ITS are expected to be in force when this amendment to install a temporary spent fuel storage rack is projected for approval, i.e., January 2007, and to provide appropriate time for NRC review, the proposed changes are presented on a marked-up draft copy of Section 4.0, "Design Features," from the MNGP ITS conversion package undergoing NRC review. Following the ITS conversion amendment approval, any resultant changes to the marked-up draft ITS pages included in Enclosure 2 will be provided.

Draft ITS Section 4.0, "Design Features," specifies, among other things, the essential features for control of fuel storage. Subsection 4.3, "Fuel Storage," places requirements on features controlling criticality in the new and spent fuel storage racks, preventing drainage of the pool, and specifying the capacity of the SFP. The following changes are proposed to the draft ITS for installation of the additional temporary PaR 8 x 8 high-density spent fuel storage rack in the SFP:

a) Revise Subsection 4.3.1, "Criticality," under Item 4.3.1.1.d, to:

- add a phrase specifying the nominal center-to-center distance between fuel assemblies in the temporary PaR 8 x 8 high-density spent fuel storage rack module.
- add the phrase "13 x 13" to distinguish between the existing high-density and temporary PaR 8 x 8 high-density spent fuel storage rack modules.
- add the word "nominal" to clarify the center-to-center distance between fuel assemblies in the low-density GE spent fuel storage rack.

b) Revise Subsection 4.3.3, "Capacity," to increase the number of fuel assemblies allowed to be stored in the SFP from 2237 to 2301.

With the proposed changes, the draft ITS Subsection 4.3.1, "Criticality," and Subsection 4.3.3, "Capacity," will read (changes underlined below):

4.3.1 Criticality

4.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

d. A nominal 6.563 inch center to center distance between fuel assemblies placed in the 13 x 13 high density storage racks, a nominal 6.625 inch center to center distance between fuel assemblies placed in the 8 x 8 high density storage rack, a nominal 6.625 center to center distance between fuel assemblies placed in the original storage rack, and a two inch gap between the high density racks and the original rack.

4.3.3 Capacity

The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 2301 fuel assemblies.

The proposed draft ITS changes are provided as marked-up pages in Enclosure 2. Retyped ITS pages will be provided to the NRC Project Manager prior to amendment issuance at his direction. No TS Bases changes are associated with this proposed LAR.

4.0 SUMMARY DESCRIPTION OF SPENT FUEL POOL / EXISTING FUEL RACKS AND PROPOSED ADDITIONAL TEMPORARY FUEL STORAGE RACK

The SFP at the MNGP is constructed of reinforced concrete with a depth and volume sufficient to provide for shielding and heat removal from the spent fuel. The reinforced concrete walls of the SFP are several feet thick.[5] The walls and floor of the SFP are lined with a stainless steel liner. This liner serves only as a watertight boundary, not as a structural member.

The original capacity of the SFP was 740 fuel assemblies. In 1977 the SFP was re-racked with thirteen (169 cell) free-standing High Density Fuel Storage System (HDFSS) modules which use Boral as a neutron poison. One original GE (20 cell) low-density rack and two control blade racks were retained (Reference 1). This increased the spent fuel storage capability to 2217 spent

5 SFP related information which may be security sensitive is available for NRC review but is not provided as part of this LAR.

fuel storage locations. Of these, only 2209 are useable due to configuration limitations at 8 locations.

Existing Low-Density Fuel Storage Rack (2 x 10)

One General Electric low-density fuel storage rack with 20 storage cells.

Existing High-Density Fuel Storage System Modules (13 x 13)

The existing high-density free-standing fuel storage rack modules are constructed of stainless steel rectangular tubes with an inner core of Boral neutron absorbing material at alternating cell locations. Each HDFSS module consists of a 13 by 13 array of tubes, approximately 7 feet on a side and 14 feet high. Each fuel storage rack module, therefore, has 169 storage cells. The neutron poison containing rectangular fuel storage tubes were fabricated by forming an inner and outer sheet of 304 stainless steel sandwiching a core of Boral (clad by aluminum). Each high-density fuel rack module provides storage cells for spent fuel assemblies on a nominal 6.563 inch center-to-center spacing.

Description of the Proposed Additional Temporary PaR High-Density Fuel Storage Rack Module

The proposed additional temporary 8 x 8 high-density fuel storage rack is free-standing and is constructed of bolted anodized aluminum with a Boral neutron absorber in an aluminum matrix core clad with 1100 series aluminum at alternating cell locations. The high-density spent fuel storage rack module was manufactured by the PaR Systems Corporation. The module consists of an 8 by 8 array of tubes. The absorber material is sealed within two concentric square aluminum tubes. The rack is approximately 4.5 feet-square by 14 feet high. Nominal fuel element center-to-center spacing is 6.625 inches.

The additional temporary PaR 8 x 8 high-density fuel storage rack module will be temporarily installed, if required, on the cask pad in the SFP.

5.0 TECHNICAL ANALYSIS

5.1 Heavy Loads

NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," provides guidelines and recommendations to assure safe handling of heavy loads by prohibiting, to the extent practicable, heavy load travel over stored spent fuel assemblies, fuel in the reactor core, safety-related equipment, and equipment needed for decay heat removal. The main hoist of the Reactor Building overhead crane will be used for handling operations involving installation / removal of this temporary high-density fuel storage rack. The main hoist of the Reactor Building overhead crane is single-failure proof and was approved by the NRC in a Safety Evaluation dated May 19, 1977 (Reference 3). The approximate weight of the individual components and the approximate maximum lift weight during installation / removal of this PaR high-density fuel storage rack module are:

Item	Weight (lbs)
PaR (8 x 8) High-Density Fuel Storage Rack Module	10,000
Lifting Rig	2,800
Rigging	500
Total Lift	12,500

The main hoist (single-failure proof) of the Reactor Building overhead crane capacity is rated at 85-tons and is therefore qualified to handle the weight of the PaR Systems high-density spent fuel storage rack.

If a FCOL is required, this temporary PaR high-density spent fuel storage rack will be placed on the cask pad in the SFP. This area is approximately 7 feet 8 inches by 7 feet which provides adequate space for the approximately 4.5 by 4.5 square-foot PaR 8 x 8 high-density fuel storage rack module.

5.1.1 NUREG-0612 Section 5.1.1

NUREG-0612 endorses a defense-in-depth approach for handling of heavy loads near spent fuel and safe shutdown systems. General guidelines for overhead handling systems used to handle heavy loads in the area of the reactor vessel and SFP are given in Section 5.1.1 of NUREG-0612. These guidelines apply to the Reactor Building overhead crane. The guidelines are:

(1) define safe load paths and have them reviewed by the plant safety review committee;
(2) develop procedures for load handling operations;
(3) train and qualify crane operators in accordance with Chapter 2-3 of American National Standards Institute (ANSI) B30.2-1976, "Overhead and Gantry Cranes;"
(4) use special lifting devices that meet the guidelines in ANSI N14.6-1978, "Standard for Special Lifting Devices for

Shipping Containers Weighing 10,000 Pounds or More for Nuclear Materials;"

(5) install and use non-custom lifting devices in accordance with ANSI B30.9-1971, "Slings;"

(6) inspect, test, and maintain cranes in accordance with Chapter 2-2 of ANSI B30.2-1976; and

(7) design cranes in accordance with Chapter 2-1 of ANSI B30.2-1976 and Crane Manufacturers Association of America document CMAA-70, "Specification for Electric Overhead Traveling Cranes."

A heavy load at the MNGP is defined as any load greater than 1100 lbs. over the SFP and the reactor core, and 1500 lbs. in other areas of the plant. Since the dry weight of the temporary PaR 8 x 8 high-density spent fuel storage rack module is approximately, but less than 10,000 pounds, installation and removal of this temporary fuel storage rack module involves handling of a heavy load over the SFP. This process will be performed consistent with the MNGP's Heavy Loads Program. The NRC staff has previously concluded that the MNGP program for control of heavy loads is in compliance with the guidelines of NUREG-0612 (see Reference 4). The following summarizes the MNGP program attributes in response to the NUREG-0612 elements identified herein.

<u>Safe Load Paths, NUREG-0612, Section 5.1.1(1)</u>

Safe load paths for the Reactor Building overhead crane are procedurally defined and reviewed by the Plant Operations Review Committee (PORC). Movement of the temporary PaR high-density spent fuel storage rack module will conform to the specified safe load path requirements. The temporary spent fuel storage rack module will not be suspended over any portion of the SFP containing spent fuel assemblies during installation.

<u>Procedures, NUREG-0612, Section 5.1.1(2)</u>

Although existing MNGP procedures covering the handling of heavy loads are adequate for handling of the temporary PaR 8 x 8 high-density spent fuel storage rack module, these procedures will be augmented as necessary to emphasize this specific task as part of the NMC modification process to be used for this temporary installation.

These procedures will be comprehensive with respect to load handling, exclusion areas, equipment required, inspection and acceptance criteria before load movement, and steps / sequence to be followed during load movement, as well as defining safe load paths and special precautions.

Crane Operators, NUREG-0612, Section 5.1.1(3)

Crane operators are trained and qualified for the tasks they perform, and perform their duties in accordance with procedures that are in compliance with ANSI B30.2-1976. Any special training required will be identified and implemented as part of the NMC modification process.

Special Lifting Devices, NUREG-0612, Section 5.1.1(5)

The PaR fuel storage rack lifting rig is similar to the rigs used in the initial SFP rack installation and subsequent re-racking in 1977 for high-density fuel storage racks at the MNGP. Any special lifting devices necessary for this installation will meet the criteria of ANSI N14.6.

Slings, NUREG-0612, Section 5.1.1.(5)

Slings used in conjunction with the Reactor Building overhead crane comply with the requirements of ANSI B30.9-1971. Slings have a minimum safety factor of 5. Slings are not derated for dynamic loading since these loads are a small percentage of the overall static load and can be disregarded.

Crane Inspection Testing and Maintenance, NUREG-0612, Section 5.1.1(6)

Inspection, testing, and maintenance of the Reactor Building overhead crane complies with ANSI B30.2-1976.

Reactor Building Overhead Crane Design, NUREG-0612, Section 5.1.1(7)

NUREG-0612, Section 5.1.1(7) suggests that cranes should be designed to meet the applicable criteria and guidelines of Chapter 2-1 of ANSI B30.2-1976, "Overhead and Gantry Cranes," and of CMAA-70, "Specifications for Electric Overhead Traveling Cranes". The Reactor Building overhead crane was manufactured prior to issuance of CMAA-70 and ANSI B30.2, and was designed to EOCI 61, "Specification for Electric Overhead Traveling Cranes," a precursor to CMAA-70. The NRC concluded that since the Reactor

Building overhead crane met the criteria for a single-failure proof crane (i.e., met the applicable provisions of draft Regulatory Guide 1.104), and therefore the applicable NUREG-0612 guidelines had been met (see Reference 4).

Based on the application of the MNGP heavy loads program, in-conjunction with the single-failure proof nature of the Reactor Building overhead crane main hoist, theré is adequate assurance that the installation / removal of the temporary PaR 8 x 8 high-density spent fuel storage rack will be accomplished consistent with the "defense-in-depth" approach to safety in the handling of heavy loads described in NUREG-0612, Section 5.1.1.

5.2 Seismic and Structural Design

The SFP is designed to withstand earthquake loadings as a Class 1 structure. It is a reinforced concrete structure, completely lined with seam-welded stainless steel plates welded to reinforcing members embedded in concrete.

Structural evaluations of the SFP, including the walls, floor, and liner, considered loads due to dead weight, live loads, hydrostatic and hydrodynamic forces, seismic inertia, thermal expansion, and mechanical accidents. Structural evaluations of the SFP were performed for the floor loading with a resulting design floor capacity of 2.7 ksf using a concrete strength of 6.4 ksi. The existing fully loaded rack floor loading is 2.1 ksf. With the addition of one fully-loaded PaR 8 x 8 high density spent fuel storage rack module the resultant floor loading will remain less than the design capacity (will not exceed 2.2 ksf).

Seismic and stress analyses for the existing SFP rack configuration are based on Regulatory Guide 1.92. A seismic evaluation of the existing storage racks was done using a SFP floor acceleration of 3.0g SSE, which is well above the MNGP SFP floor acceleration of 0.2g SSE. Modeling of the fuel storage rack module was developed for each structural component. The modules were combined into an idealized 8-module array and the pool wall was included to determine hydrodynamic mass effects. The modules were analyzed as a cantilevered beam attached to a rigid base to derive loads in a water filled rectangular pool. These loads were derived for the horizontal and vertical accelerations and compared to allowable stresses. Additionally, frictional forces and seismic overturning moments were evaluated and found to cause no instabilities under any storage conditions. These studies also confirmed that interaction between the fuel storage modules would be negligible when subjected to SSE conditions. The maximum horizontal displacement of the modules was calculated to be 0.07 inch. Nominal spacing between modules is approximately 2 inches. Accordingly, no interaction between modules will occur under accident conditions.

The additional temporary PaR 8 x 8 spent fuel storage rack module was evaluated using time history analyses that are conservative with respect to Regulatory Guides 1.60 and 1.61. The information discussed in this section comes primarily from three sections of a PaR report for which the applicable portions for the MNGP unit are provided in Enclosure 3. These three sections are listed below. The time history analyses performed for the Duane Arnold Energy Center (DAEC) (the original rack procurer) have been reviewed by NMC and found to bound the MNGP seismic design criteria.

- Section 5.3 Model Description, Formulation and Assumptions for the Seismic Analysis of BWR Spent Fuel Racks
- Section 5.4 Dynamic Time History Analysis of Spent Fuel Racks
- Section 5.5 Module Stress Analysis

The PaR rack structure simplified dynamic model attached to a horizontal beam was modeled as a planar frame consisting of a cantilever beam at the base, with leg beam connections to the floor. For worst-case analysis, it is assumed that all fuel in the Par rack was channeled which provided the highest loads. This model also conservatively assumed that all fuel assemblies are in phase and move together. The following assumptions were made relative to the PaR rack submergence in the SFP:

(1) all water entrapped within the fuel rack envelope is added to the horizontal mass but not to the vertical mass;
(2) due to the water depth above the fuel rack, surface waves and sloshing effects are ignored; and
(3) external water effects between the fuel rack and the walls are ignored, which conservatively assumes that damping forces resulting from the confined water as a result of the relative motion of the fuel rack is greater than external mass effects of this water.

Displacements and loads resulting from the response of the additional temporary PaR high-density spent fuel storage rack to seismic events were calculated for the DAEC for simultaneous vertical and horizontal SSE motion using conservative time histories. The maximum sliding displacement of the PaR high-density spent fuel storage rack relative to the SFP floor was determined to be approximately 1.05 inches for an empty rack. The temporary PaR fuel rack, if installed at the MNGP will be on the cask pad in the SFP and the spacing to adjacent structures will not be less than 6 inches, consequently no interaction with adjacent structures was considered. The analysis showed that the PaR high-density spent fuel storage rack is capable of withstanding the loads associated with all design loading conditions without exceeding allowable stresses. The analysis also indicates that the PaR high-density spent fuel storage rack will withstand overturning moments and horizontal forces without structural attachment to the SFP. The maximum computed stress was less than 80 percent of the allowable stress and located at the interior of the top casting.

5.3 Thermal-Hydraulic Considerations

5.3.1 Spent Fuel Pool Cooling System Description

The SFP pool cooling system configuration and design basis are described in the MNGP USAR Section 10.2.2.2.

The SFP cooling system consists of circulating pumps, heat exchangers, filters, piping, valves and instrumentation. The pumps take suction from the skimmer surge tank, which continuously skims the water at surface level, and circulates the water through the heat exchangers prior to discharge of the water through diffusers located near the bottom of the SFP. Provision is made for utilization of the RHR System for additional/backup heat removal capacity. The piping of the SFP cooling system is arranged so that failure of any pipe will not drain the SFP below the level required for acceptable radiation shielding.

5.3.2 Current SFP Cooling System Licensing Basis

The current licensing basis is summarized in MNGP USAR Section 10.2.2.3.

The existing analyses supporting the SFP cooling system licensing basis include evaluations for a normal maximum heat load based on a partial core offload of 141 assemblies discharged every 18 months, and an emergency heat load based on a FCOL thirty (30) days following a refueling outage which fills the last 484 storage locations in the SFP.

For the normal case, the SFP cooling and/or RHR systems were determined to be adequate to control heat removal and consistently maintain a water temperature entering the coolers of not more than

125°F. The maximum bulk water temperature for the SFP was calculated to be less than 115°F, maximum cladding temperature was 120.3°F, and maximum Boral temperature in the storage tube was less than 105°F. For the loss-of-cooling case, although MNGP does have RHR system cooling availability, three conditions were evaluated. The worst case scenario for this analysis was determined to be a full core discharge wherein the pool reaches boiling in approximately 10.3 hours. The maximum evaporation rate after bulk boiling commences is 43 gpm. The minimum elapsed time period of 10.3 hours is sufficient to establish a corresponding makeup rate from the RHR Service Water System or other coolant source.

The removal of heat for the emergency heat load scenario is accommodated by use of either the spent fuel cooling and demineralizer system or by the RHR system. FCOL analyses for the period immediately following the end of hot full power operation are most relevant due to the bounding decay heat of the offloaded fuel. This scenario is explicitly calculated and compared to cooling capabilities prior to any fuel movement that would increase the SFP heat load.

As discussed above, MNGP's normal refueling analyses also considers the scenario that includes the effects of a full core offload. Administrative controls are in place to ensure that the bulk SFP temperature does not exceed 140°F for any offload scenario.

5.3.3 Additional Temporary Spent Fuel Storage Rack Thermal Hydraulic Analyses

This section summarizes the thermal-hydraulic analysis performed by NMC to demonstrate that SFP cooling is maintained within the current licensing basis.

The temporary PaR 8 x 8 high-density spent fuel storage rack will be installed just prior to Refuel Outage 23 (RFO-23) or during Cycle 24 if needed to perform a FCOL. The thermal-hydraulic analysis is based on the evaluation of three offload scenarios that bound the past and future operating practices at MNGP:

(1) a partial core offload scenario;
(2) a full core offload; and
(3) an emergency full core offload (484 spent fuel assemblies) beginning 150 hours after shutdown from full power operation with no coastdown.

The number of irradiated fuel assemblies assumed to be stored in the SFP in each of the evaluated scenarios conservatively bounds the actual number of irradiated fuel assemblies that are expected to be stored in the SFP with the addition of the temporary PaR 8 x 8 high-density spent fuel storage rack installed.

These scenarios have been evaluated with a base decay heat load contribution from the previously discharged fuel assemblies. The contribution to the base decay heat load from fuel that has been discharged prior to Cycle 23 is based on the actual fuel assembly burnup and operating power. Operating cycle length increased from 18 to 24 months beginning with Cycle 23.[(6)] With the increase in cycle length, the assumed nominal cycle discharge increased from 141 to 152[(7)] assemblies.

Each of these offload scenarios assumes a core offload that is completed 150 hours after reactor shutdown and incorporates conservative fuel assembly discharge and burnup assumptions.

The evaluation shows that the heat loads anticipated for the SFP can be adequately cooled by either the normal fuel pool cooling system or by the RHR cooling connection to the SFP.

The evaluation included the following characteristics:

1. ANSI/ANS-5.1-1994 decay heat correlation was used to calculate the point where the most limiting emergency heat load would be expected to occur during an operating cycle.
2. ANSI/ANS-5.1-1994 decay heat correlation was used to calculate the decay heat of all fuel bundles currently in the SFP at the most limiting times after future anticipated discharges, for both the normal and emergency cases.
3. Decay heat of future anticipated discharge bundles was determined using the ANSI/ANS-5.1-1994 decay heat correlation.
4. A one-sided 95 percent confidence interval was included.
5. Basis for decay heat of future discharges is a reactor power level of 1880 Mwth. (The current licensed power level of the MNGP reactor is 1775 Mwth).

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6 The 24-month operating cycle is nominally assumed to be 23-months of power operation with a refueling outage length of 30 days.

7 Variations in nominal discharge size are bounded by the additional number of bundles assumed in the thermal-hydraulic analyses for conservatism (Item 9 - following page).

6. Future operating nominal cycle lengths of 23 months of power operation with a refueling outage length of 30 days. Coastdown intervals assumed to be 30 days.
7. The assumed number of discharge bundles for future cycle operation was assumed to be 152 (nominal value). Normal variations in discharge size are bounded by an additional number of bundles assumed in the thermal-hydraulic analyses for conservatism (see Item 9 below).
8. The offloading of spent fuel assemblies from the SFP to the ISFSI was considered in the analysis. A total of 7 NUHOMS 61-BT casks were assumed to be loaded during the period (these casks are expected to be used for the MNGP ISFSI).
9. Assumed an additional spent fuel storage capacity of 149 fuel bundles (versus 64 fuel bundle increase being requested).
10. Decay heat due to the activation of fuel bundle structural components, as described in GE SIL 636.
11. Mississippi river temperature assumed to be 90°F, the maximum value used at MNGP for the cooling water source temperature.
12. The analysis compared the resulting non-emergency SFP heat loads to the heat removal capability currently defined in USAR Section 10.2.2.3.
13. The analysis compared the resulting emergency heat loads to the heat removal capability of the RHR system.

This evaluation resulted in the following calculated fuel pool decay heat loads:

- Normal discharge, 96 hours after shutdown: 7.25 MBTU/hr
- Normal discharge, 216 hours after shutdown: 5.55 MBTU/hr
- Emergency FCOL, 150 hours after shutdown: 24.71 MBTU/hr

The USAR Section 10.2.2.3 heat load of 5.60 MBTU/hr will be met 216 hours (9 days) after a shutdown.

The projected decay heat due to an emergency FCOL is less than the worst case heat removal capability of the RHR system of approximately 26.4 MBTU/hr with 90°F Mississippi river water.

5.3.3.1 SFP Cooling System Performance Data

The calculated heat removal rate from the SFP varies with time as a function of several independent variables, including flow rates, temperatures, and heat exchanger fouling and tube plugging.

During emergency operation of the fuel pool cooling system, the RHR heat exchanger is available to provide cooling for the SFP. In the SFP the water is heated by the decay heat from the spent fuel bundles as it flows from the fuel pool to the skimmer tanks, and then to the RHR heat exchanger where it is cooled. This flow is the RHR heat exchanger process flow. In addition to this RHR heat exchanger process water, water flows from the Mississippi River and through the heat exchanger to cool the process flow, and then flows back to the river. The SFP is assumed to be at the maximum temperature of 140°F. Cooling water flow is assumed to be at the maximum allowed temperature of 90°F. Evaporative cooling was neglected. Consequently, the sole source of cooling for the SFP is RHR heat exchanger duty.

Conservative values for pump flow and heat exchanger performance were selected to provide bounding calculations for the peak SFP bulk temperature. The thermal performance of the heat exchangers was determined with all heat transfer surfaces assumed to be fouled to their design basis maximum levels and included an allowance for 5 plugged tubes.

5.3.3.2 <u>SFP Decay Heat Load</u>

The SFP bulk temperature analysis requires quantifying the total decay heat load as a function of time after reactor shutdown and core offload time. The total decay heat load imposed on the SFP cooling system was evaluated as the sum of two decay heat sources:

- decay heat from previous offloads already stored in the pool, and
- decay heat from the fuel assemblies recently offloaded from the reactor.

The decay heat load from previously offloaded fuel was calculated using the ANS1994v1.3 computer program. Inputs to the program are based on known power histories for discharged fuel and a projected fuel offload schedule that conservatively bounds both fuel assembly burnup and the number of fuel assemblies to be offloaded. The decay heat load calculations include a one sided 95% confidence interval based on a power level of 1880 Mwth (licensed power level is 1775 Mwth). In addition, decay heat load due to the activation of fuel bundle structural components was included.

Normal fuel offloads are assumed to be complete 216 hours after reactor shutdown. Conservative assumptions were made with respect to operating power and fuel burnup to determine a bounding decay heat load contribution for the offloaded fuel.

For each scenario, the decay heat of the current SFP configuration and the decay heat of future discharges were combined to provide a total decay heat load on the SFP cooling system.

5.3.3.3 Maximum SFP Bulk Temperatures

The SFP bulk temperature versus time was calculated for each offload scenario based on the time-varying total decay heat load on the SFP cooling system. The calculations also included several conservative assumptions regarding heat exchanger fouling and tube plugging, SFP thermal capacity, reactor power, and bounding core offload parameters.

All core offload analyses resulted in a maximum pool bulk temperature of less than 140°F.

Therefore, with the temporary PaR 8 x 8 high-density spent fuel storage rack installed, the SFP peak bulk temperature remains within the current licensing basis maximum of 140°F for all offload scenarios. As with the current licensing basis, MNGP will continue to maintain administrative controls in place to ensure that peak SFP temperatures remain below 140°F during the normal full core offload scenario.

5.3.3.4 Minimum Time-to-Boil and Maximum Boil-off Rate

If SFP cooling capability is lost, the minimum possible time to achieve bulk pool boiling has been calculated to be 10.3 hours. The maximum evaporation rate after bulk boiling commences is 43 gpm. A bulk SFP boiling time of 10.3 hours provides sufficient time to establish a makeup rate from the RHR Service Water System in excess of 43 gpm. Under bulk boiling conditions the temperature of the fuel does not exceed 350°F.

Diverse means of identifying a loss of SFP cooling are available to the operators. The SFP cooling system can be controlled from either a local panel in the Reactor Building or a remote panel in the Radwaste Building. Plant operators are provided with indications and/or alarm of system flow, pool water level, water temperature, skimmer surge tank temperature, skimmer surge tank level, and valve positions. Initial filling and maintenance of the SFP and surge tanks is from the condensate storage and transfer system.

Based on the control systems in place, the number and diverse sources of makeup water available, loss of SFP makeup capability is not considered credible.

In conclusion, installation of the temporary PaR 8 x 8 high-density spent fuel storage rack does not add significant cooling requirements to the existing configuration. The present heat removal systems have adequate capacity to maintain the SFP temperature within the current temperature limits specified for MNGP. Additionally, the safety-related RHR system is designed to serve as a backup cooling system.

5.3.4 Administrative Controls

Plant procedures limit the peak SFP temperature to within the 140°F limit discussed in USAR Section 10.2.2. The procedural controls suspend offload activities at a SFP temperature of 125°F to maintain peak SFP bulk temperatures less than 140°F.

Due to the many variables that can have an impact on peak SFP temperature, MNGP performs a cycle specific offload analysis to confirm the applicability of the bounding thermal analyses described above. Consideration is given to the actual core power history and SFP inventory for the cycle specific evaluation.

5.4 Radiological Assessment

5.4.1 Radiation Protection and ALARA Considerations

The existing radiation protection programs at the MNGP are adequate for rack installation operations. The operations involved in the installation and removal of the temporary PaR 8 x 8 high-density spent fuel storage rack will be controlled by procedures. These procedures are based on the principle of keeping doses As Low As Reasonably Achievable (ALARA), consistent with the requirements of 10 CFR 20.

During the installation and removal of the temporary PaR high-density spent fuel storage rack, exposures will be maintained ALARA consistent with the requirements of 10 CFR 20 and the plant's ALARA program. Similar operations have been performed at a large number of facilities (including MNGP) and experience indicates that the task of installing fuel storage racks in locations not previously occupied by other racks can be accomplished with minimum radiation exposure to personnel. Based on the SFP configuration and the design of the fuel storage rack which allows remote installation, it has been determined that diving operations are not required for the installation and removal. Radiation Work Permits (RWP's) will be prepared to control the various in-pool and out-of-pool activities. The RWPs and planning documents will provide appropriate radiological controls to complete the work.

Involved personnel receive radiation protection training consistent with the requirements of 10 CFR 19. Specific information, such as the potential for extremity doses when removing and decontaminating items from the SFP, and operating experience with SFP activities is discussed in pre-job briefings. The radiation protection technicians participate in pre-job briefings involving activities associated with installation and removal.

5.4.2 Occupational Exposures

The impact on the occupational dose from spent fuel pool operations during the installation and removal of the temporary PaR 8 x 8 high-density spent fuel storage rack is expected to be minimal. Based on previous experience at MNGP with fuel rack installation and removal, the process will not create significant radiological waste or personnel exposure.

Since the airborne radioactivity and water activity will not significantly increase, no design or capacity changes in the SFP ventilation system or SFP water cleanup systems are needed for radiological reasons. Similarly, the radiation monitoring system for the SFP, as described in the USAR, is adequate.

5.4.3 Fuel Handling Accident (FHA)

This section reviews the impact of installing the temporary PaR 8 x 8 high-density spent fuel storage rack on the probability and radiological consequences of a Fuel Handling Accident (FHA).

The current licensing basis FHA considers a fuel bundle that is dropped on top of the core resulting in damage to 125 fuel rods. This accident scenario is described in USAR Section 14.7. Table 1 presents the results for this scenario with the current licensing basis assumptions. Key assumptions in this scenario include, but are not limited to, a normal operating power of 1880 MWt (plus uncertainties), accident occurrence 24 hours after shutdown, damaged rod peaking factor of 1.5, and instantaneous airborne release to the environment with no hold up in the reactor building.

Table 1 – Current Fuel Handling Accident Radiological Consequence Analysis Results

Current FHA Analysis	Offsite Dose				Control Room Dose
	EAB (rem)		LPZ (rem)		
	Thyroid	Whole Body	Thyroid	Whole Body	
Refueling Accident Current Analysis	2.04	0.192	0.71	0.067	Not calculated
Regulatory Acceptance Limit (10 CFR 100)	300	25	300	25	Not calculated

On April 29, 2004, NMC submitted a LAR proposing a selective scope application of an alternative source term (AST) for the FHA (and later provided additional information) in accordance with the provisions of 10 CFR 50.67, "Accident Source Term" (References 5 and 6). Table 2 presents the results with the proposed AST FHA licensing basis assumptions.

Table 2 – AST Fuel Handling Accident Radiological Consequence Analysis Results

Proposed AST FHA Analysis	Offsite Dose		Control Room Dose (rem TEDE)
	EAB (rem TEDE)	**LPZ** (rem TEDE)	
Refueling Accident Inside Containment	1.81	0.37	4.71
AST Regulatory Acceptance Limit (10 CFR 50.67)	6.3	6.3	5

The results of both the current FHA and proposed AST FHA licensing basis analyses indicate that the dose at the Exclusion Area Boundary (EAB) and the Low Population Zone (LPZ) would be well within the applicable regulatory acceptance criteria set forth in the Standard Review Plan or Regulatory Guide 1.183, respectively. The dose to the Control Room operators is also less than the specified regulatory acceptance criteria.

The installation / removal of this temporary PaR 8 x 8 high-density spent fuel storage rack will involve the same water depth as the existing fuel racks providing the same iodine decontamination factors assumed in the FHA analysis.

Since the source term for the spent fuel inventory is much less than the conservative assumptions made in the existing USAR analysis, the radioactivity released from a fuel assembly dropped over the temporary PaR high-density spent fuel storage rack will remain less than the existing design basis fuel handling accident. Consequently, the existing FHA analysis remains bounding.

The probability of a FHA occurring by the addition or removal of this additional temporary PaR high-density spent fuel storage rack is not significantly increased because the same equipment (e.g., the spent fuel handling crane), procedures and controls will be used to handle fuel assemblies. This fuel movement does not significantly increase the normal frequency of fuel movement in the SFP such as refueling outage and non-outage fuel shuffles.

5.4.4 Radiological Summary

No significant increase in radiation exposure to operating personnel is expected as a result of adding the temporary PaR 8 x 8 high-density spent fuel storage rack; therefore, neither the current health physics programs nor the area monitoring systems need to be modified.

5.5 Criticality

NMC is obtaining a spare PaR 8 x 8 high-density spent fuel storage rack from another nuclear power plant and plans to install it in the SFP if a situation were to arise requiring a FCOL. NMC has performed a preliminary assessment of the PaR fuel rack criticality design information. Based on this preliminary assessment, the PaR fuel rack performance from a criticality perspective is acceptable. To confirm this assessment, NMC will provide an MNGP specific criticality evaluation for the 8 x 8 PaR high-density spent fuel storage rack as a supplement to this LAR.

5.6 Accidents and Events Evaluated

5.6.1 Structural Evaluation of the Additional High-Density Spent Fuel Storage Rack During Postulated Fuel Assembly Drop Events

The NRC "OT Position Paper for Review and Acceptance of Spent Fuel Storage and Handling Applications" specifies that spent fuel storage rack designs must ensure the functional integrity of racks under all credible fuel assembly drop events.

The information discussed in this section comes primarily from two sections of a PaR report, for which the applicable portions for the MNGP temporary rack are provided in Enclosure 3. The sections are entitled:

- Section 5.6 Equivalent Static Loads for Fuel Impact Conditions
- Section 5.7 Dropped Fuel Bundle Analysis

Shallow Drop Scenario

A "shallow drop" of a fuel assembly occurs when the dropped assembly strikes the top of the fuel rack and damages the honeycomb structure, but does not enter an open cell or land directly in a cell already containing a stored fuel assembly. The structural acceptance criterion for this event is that the damage to the fuel rack structure must be limited to the portion of the cell(s) above the top of the active fuel region for the stored fuel assemblies. The assumed free-fall height for this event is from 18 inches above the rack.

Assuming a minimal impact area, the analysis shows that the top of the impacted cell undergoes localized plastic deformation to a depth which remains above the top of the active fuel region. Therefore, the functional integrity of the temporary PaR high-density spent fuel storage rack is maintained.

Deep Drop Scenario

A "deep drop" of a fuel assembly occurs when the dropped fuel assembly enters an empty storage cell and impacts the base of the high-density fuel storage rack. Local failure of the base is acceptable, however the fuel rack design should ensure that gross structural failure does not occur and that the subcriticality of adjacent fuel assemblies is not violated.

The analysis shows that the deep drop of a fuel assembly through an interior cell will not result in a change in spacing (pitch) between cells. Local deformation of the baseplate in the area of impact will occur, but the dropped assembly will be contained and not impact the SFP liner (i.e., the temporary PaR high-density spent fuel storage rack will be placed on the cask pad, if installed).

5.6.2 Operational Errors and Mishandling Events

The probability of an operational error occurring during fuel handling activities associated with the additional temporary PaR high-density spent fuel storage rack is not significantly increased because the same equipment, procedures, and controls that are normally used for handling fuel will be utilized. During the rack installation activity, specific procedures and controls (including an ALARA Plan and Heavy Load Program) will be used to protect personnel, equipment, and the design basis of the SFP.

Section 5.4.3 discusses the radiological impacts from a FHA and concludes that the consequences are bounded by the existing analysis contained in Section 14.7 of the USAR.

5.6.3 Tornados

The impacts of tornados and tornado-borne missiles on structures at the MNGP has been evaluated and is described in USAR Section 2.3. The evaluation concluded that adequate protection against tornado wind forces and tornado-generated missiles has been provided.

Based on the above information, specific evaluation of these events is not required for the installation of the additional temporary PaR 8 x 8 high-density spent fuel storage rack module in the SFP.

6.0 REGULATORY ANALYSIS

The Monticello Nuclear Generating Plant (MNGP) has a spent fuel pool (SFP) with a licensed spent fuel storage capacity of 2237 fuel bundles, providing capacity for fuel storage while maintaining full core offload capacity through 2006. While not a regulatory requirement, the Nuclear Management Company (NMC) considers it prudent to maintain the ability to fully off-load the MNGP reactor core. Beginning with the staging of new fuel prior to the Cycle 23 refueling outage in the spring of 2007, MNGP will lose full core offload (FCOL) capability. To ensure sufficient spent fuel storage capacity continues to exist at the MNGP, NMC is obtaining a Programmed and Remote (PaR) Systems 8 x 8 (64 cell) high-density spent fuel storage rack whose design incorporates Boral™ as a neutron absorber in the cell walls. This rack will be installed in the event a FCOL is required. This temporary fuel storage rack will extend FCOL capability until 2008, at which time an Independent Spent Fuel Storage Installation (ISFSI) is expected to become operational at the MNGP.

NMC has performed a preliminary assessment of the PaR fuel rack criticality design information and determined that the criticality performance of the PaR fuel rack is acceptable. NMC will provide an MNGP specific criticality evaluation including a no significant hazards consideration determination with respect to criticality in a separate submittal.

6.1 No Significant Hazards Consideration

NMC has evaluated whether a significant hazards consideration is involved with the proposed changes by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below:

1) **Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?**

Response: No.

This proposed temporary increase in the storage capacity of the SFP has been reviewed for the effects on the existing fuel handling equipment and procedures, the SFP cooling system and pool cooling capability, seismic events, and fuel handling accidents or accidents involving heavy loads. The mechanics for performing fuel movements, including those associated with this modification are unchanged, and will be accomplished in accordance with the existing fuel handling procedures. Consequently, the probability of dropping a fuel assembly during individual fuel movement is not increased.

The main hoist of the Reactor Building overhead crane is single-failure proof and the design has been reviewed and approved by the NRC. It has more than sufficient rated capacity to install / remove the temporary PaR spent fuel storage rack module with an ample safety factor margin. The heavy loads guidelines specified in NUREG-0612 are also applied to further reduce the potential for a heavy load drop. Heavy loads are not moved directly over spent fuel without prior NRC approval. These considerations demonstrate that the probability of a drop of the temporary PaR spent fuel storage rack module (a heavy load) is extremely small.

Accordingly, the proposed modification does not involve a significant increase in the probability of an accident previously evaluated.

The consequences of a fuel handling accident during this modification have been considered. NMC found that there is no significant change in the radiological consequences of a fuel assembly drop from the previous analyses. The calculated doses are well within 10 CFR 100 guidelines. Therefore, the consequences of a fuel handling accident are not significantly increased from previously evaluated events.

The consequences of a loss of spent fuel pool cooling system flow have also been evaluated and it was determined that there is sufficient time available to provide an alternate means for cooling the SFP in the event of a complete failure of the normal cooling system. Thus, the consequences of loss of cooling system flow are not significantly increased from those previously evaluated.

The consequences of a seismic event have been evaluated. The additional temporary PaR spent fuel storage rack has been designed and fabricated to meet the requirements of the applicable NRC Regulatory Guides and published standards. The temporary PaR and existing high-density spent fuel racks are free-standing racks, so that the integrity of the racks and the pool structure is maintained during and after a seismic event (Safe Shutdown Earthquake). Thus, the consequences of a seismic event are not increased from that previously evaluated.

The probability and consequences of a spent fuel cask drop are unaffected by the installation of the PaR high-density fuel storage rack.

Consequently, it is concluded that the proposed amendment to add capacity to the SFP by the addition of a temporary PaR 8 x 8 high-density spent fuel storage rack does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. **Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?**

Response: No.

NMC has evaluated the proposed modification in accordance with the guidance of the appropriate NRC Regulatory Guides, Standard Review Plan, and appropriate industry codes and standards. No unproven technology is utilized either in the construction process or in the analytical techniques necessary to justify the temporary fuel storage expansion. In fact, more extensive expansions of SFP capacity using similar technology to that proposed herein have been developed and demonstrated in many applications previously approved by the NRC. Further, MNGP has reracked the SFP previously. This much less extensive, temporary expansion of storage capability will not introduce any new accidents from those previously analyzed.

Based upon the foregoing, NMC concludes that the proposed additional temporary rack does not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. **Does the proposed amendment involve a significant reduction in a margin of safety?**

Response: No.

Guidance provided in the NRC Standard Review Plan has established that for the issue of margin of safety as applied to a spent fuel pool inventory increase (re-racking) modification should address 1) nuclear criticality, 2) thermal-hydraulic, and 3) mechanical, material and structural considerations.

An evaluation of the temporary PaR high-density spent fuel storage rack with respect to nuclear criticality is not complete to date, and accordingly, is not discussed here. A separate no significant hazards consideration determination solely concerning criticality will be provided together with the criticality evaluation as a supplement.

Conservative methods were used to calculate the maximum fuel temperature and the increase in temperature of the water in the SFP. The thermal-hydraulic evaluation used the methods previously employed for evaluations of the present spent fuel storage racks to demonstrate that the temperature margins of safety are maintained. The proposed modification results in a small increase in the heat load in the SFP. The evaluation shows that the existing spent fuel cooling system will maintain the bulk pool water temperature at or below 140°F. Thus a margin of safety exists such that the maximum allowable temperature for bulk boiling is not exceeded for the calculated increase in pool heat load. The evaluation also shows that maximum local water temperatures along the hottest fuel assembly are below that for a nucleate boiling condition to exist. Thus, there is no significant reduction in the margin of safety for spent fuel cooling concerns.

The main safety function of the SFP and the racks is to maintain the spent fuel assemblies in a safe configuration through all normal or abnormal loadings. Abnormal loadings which have been considered are the effect of an earthquake, the drop of a spent fuel assembly, or the drop of any other heavy object in the pool. The mechanical, material, and structural design of the new spent fuel racks is in accordance with the applicable NRC guidance and industry codes. The rack materials used are compatible with the spent fuel pool and the spent fuel assemblies. The structural considerations of the new racks address margins of safety against tilting and deflection or movement, such that the racks do not impact each other during the postulated seismic events and the fuel racks and spent fuel assemblies remain intact. Thus the margins of safety are not significantly reduced by the proposed amendment.

Based on the above, NMC has determined that operation of the facility in accordance with the proposed changes does not involve a significant hazards consideration as defined in 10 CFR 50.92(c), in that they: (1) do not involve a significant increase in the probability or consequences of an accident previously evaluated; (2) do not create the possibility of a new or different kind of accident from any accident previously evaluated; and (3) do not involve a significant reduction in a margin of safety.

6.2 Applicable Regulatory Requirements / Criteria

This section describes how the proposed changes and NMC's technical analyses satisfy applicable regulatory requirements and acceptance criteria. MNGP was constructed before the General Design Criteria (GDC) of 10 CFR 50 and the Standard Review Plan were promulgated. However, the concept(s), guidance, and criteria expressed by the GDC(s) and Standard Review Plan listed below were generally applicable.

- GDC-61, "Fuel storage and handling and radioactivity control" provides requirements for the residual heat removal capability of the fuel storage systems.

- GDC-62, "Prevention of criticality in fuel storage and handling," requires licensees to prevent criticality in the fuel storage and handling system by physical systems or processes, preferably by use of geometrically safe configurations.

- NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants" (SRP), Section 9.1.2, "Spent Fuel Storage."

- NUREG-0800, SRP Section 9.1.3, "Spent Fuel Pool Cooling and Cleanup System."

- NUREG-0800, "SRP Section 15.0.1, "Radiological Consequence Analysis Using Alternative Source Terms."

- NUREG-0554, "Single-Failure-Proof Cranes for Nuclear Power Plants."

- NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants."

NMC has evaluated the proposed changes against the applicable regulatory requirements and acceptance criteria as described herein. Based on these evaluations there is reasonable assurance that the health and safety of the public will be maintained after the temporary installation of an additional high-density spent fuel storage rack.

7.0 ENVIRONMENTAL CONSIDERATION

NMC has evaluated the proposed changes against the criteria for identification of licensing and regulatory actions requiring environmental assessment in accordance with 10 CFR 51.21, "Criteria for identification of licensing and regulatory actions requiring environmental assessments." NMC has determined that the proposed changes meet the criteria for a categorical exclusion as set forth in 10 CFR 51.22(c)(9), and as such, has determined that no irreversible consequences exist in accordance with 10 CFR 50.92(b), "Issuance of amendment." This determination is based on the fact that this change is being proposed as an amendment to a license issued pursuant to 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," which changes a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, "Standards for Protection Against Radiation," or that changes an inspection or surveillance requirement, and the amendment does not result in the following:

(i) A significant hazards consideration,

The proposed amendment does not involve a significant hazard. See the no significant hazards consideration determination evaluation.

(ii) A significant change in the type or significant increase in the amounts of any effluent that may be released offsite,

The proposed amendment is consistent with and does not change the design basis of the plant. The proposed amendment involves a potential temporary increase in spent fuel pool capacity in the event a full-core offload (FCOL) is required. The temporary PaR high-density spent fuel storage rack will not be installed, i.e., utilized, unless a situation arises where a FCOL is required. Installation of this temporary fuel storage rack is an interim measure to increase the spent fuel storage capacity until an on-site dry storage facility (ISFSI) can be utilized. Once the ISFSI is operational, and sufficient spent fuel assemblies have been transferred to it to support FCOL, fuel storage within the spent fuel pool will return to the presently licensed capacity of 2237 assemblies.

Even if installation of this temporary high-density spent fuel storage rack is required, it will not result in a change in the type or involve a significant increase in the amounts of any effluent that may be released offsite.

This amendment will not result in an increase in power level, and will not significantly increase the production of radioactive waste and byproducts.

The proposed amendment will not alter the flow path or method of disposal of radioactive waste or byproducts. Therefore, the proposed amendment does not involve a significant change in the type or amount of any effluent that may be released offsite.

(iii) A significant increase in individual or cumulative occupational radiation exposure.

The proposed amendment does not result in changes in the level of control or methodology used for processing radioactive effluents or handling of solid radioactive waste. Previous installations of fuel racks at this facility and plants across the country have demonstrated that the individual or cumulative occupational radiation exposure is low when good ALARA practices have been applied. There will be no change to the normal radiation levels within the plant. Therefore, the proposed amendment does not involve a significant increase in individual or cumulative occupational radiation exposure.

Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.52(c)(9). Therefore, pursuant to 10 CFR 51.22(b), an environmental impact statement or environmental assessment is not required.

8.0 REFERENCES

1. Letter from NRC to Northern States Power (NSP) Company, "Monticello Nuclear Generating Plant, Amendment to Provisional Operating License," Amendment No. 34, (increased capacity of the spent fuel storage pool from 740 to 2237 fuel assemblies), dated April 14, 1978.

2. Letter from NMC to NRC, "License Amendment Request: Conversion of Current Technical Specifications (CTS) to Improved Technical Specifications (ITS)," (L-MT-05-072), dated June 29, 2005.

3. Letter from NRC to NSP, transmitting a NRC Safety Evaluation by the Office of Nuclear Reactor Regulation Supporting Approval of the Crane Modifications and use of the 70 Ton Spent Fuel Shipping Cask IF-300, dated May 19, 1977.

4. Letter from NRC to NSP, transmitting a NRC Safety Evaluation by the Office of Nuclear Reactor Regulation to the Northern States Power Company, Monticello Nuclear Generating Plant, Control of Heavy Loads -- Phase I, dated March 19, 1984.

5. Letter from NMC to NRC, "License Amendment Request: Selective Scope Application of an Alternative Source Term Methodology for Re-evaluation of the Fuel Handling Accident," (L-MT-04-023), dated April 29, 2004.

6. Letter from NMC to NRC, "Response to Second Request for Additional Information Related to Technical Specifications Change Request to Apply Alternative Source Term (AST) Methodology to Re-Evaluate the Fuel Handling Accident (TAC No. MC3288)," (L-MT-05-011), dated February 28, 2005.

ENCLOSURE 2

PROPOSED TECHNICAL SPECIFICATION CHANGES

This enclosure consists of the proposed Technical Specification page(s). The page(s) included in this enclosure are listed below:

Specification Paragraph No. (Title if Applicable)		Page(s)
Specification 4.3.1.1.d	Criticality (specification 4.3.1)	4.0-2
Specification 4.3.3	Capacity	4.0-2

2 Pages Follow

4.0 DESIGN FEATURES

4.1 Site Location

4.1.1 Site and Exclusion Area Boundaries

The site area and exclusion area boundaries are as shown in Chapter 15, Figure ND-95208 of the USAR.

4.1.2 Low Population Zone

The low population zone is all the land within a 1 mile radius circle as shown in Chapter 15, Figure ND-95208 of the USAR.

4.2 Reactor Core

Included for Info.
No changes this page.

4.2.1 Fuel Assemblies

The reactor shall contain 484 fuel assemblies. Each assembly shall consist of a matrix of Zircalloy fuel rods with an initial composition of natural or slightly enriched uranium dioxide (UO_2) as fuel material and water rods. Some fuel rods may consist of a Zircalloy base and a zirconium inner liner. Fuel assemblies shall be limited to those fuel designs that have been analyzed with NRC staff approved codes and methods and have been shown by tests or analyses to comply with all safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in nonlimiting core regions.

4.2.2 Control Rod Assemblies

The reactor core shall contain 121 cruciform shaped control rod assemblies. The control material shall be boron carbide or hafnium metal as approved by the NRC.

4.3 Fuel Storage

4.3.1 Criticality

4.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having a maximum k-infinity of 1.33 in the normal reactor core configuration at cold conditions;

b. $k_{eff} \leq 0.95$ for high density fuel racks if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.2.1 of the USAR;

4.0 DESIGN FEATURES

4.3 Fuel Storage (continued)

c. keff ≤ 0.90 for original fuel rack if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.2.1 of the USAR; and

a nominal 6.625 inch center to center distance between fuel assemblies placed in the 8x8 high density storage rack,

13 x 13

d. A nominal 6.563 inch center to center distance between fuel assemblies placed in the high density storage racks, a 6.625 ~~center to center distance between fuel assemblies placed~~ in the original storage rack, and a two inch gap between the high density racks and the original rack.

nominal

4.3.1.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having a maximum k-infinity of 1.31 in the normal reactor core configuration at cold conditions;

b. k_{eff} < 0.90 if dry;

c. k_{eff} < 0.95 if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 10.2.1 of the USAR;

d. k_{eff} ≤ 0.98 under optimum moderator conditions, which includes an allowance for uncertainties as described in Section 10.2.1 of the USAR; and

e. A minimum 6.5 inch center to center distance between fuel assemblies placed in storage racks within a row and a minimum 10 inch center to center distance between fuel assemblies placed in storage racks between rows.

4.3.2 Drainage

The spent fuel storage pool is designed and shall be maintained to prevent inadvertent draining of the pool below elevation 1003 ft 7.25 inches.

4.3.3 Capacity

2301

The spent fuel storage pool is designed and shall be maintained with a storage capacity limited to no more than 2237 fuel assemblies.

ENCLOSURE 3

PaR SYSTEMS DESIGN REPORT

This enclosure provides copies of the applicable sections of a design report produced originally for the Duane Arnold Energy Center providing information on the design and analyses supporting the PaR high-density spent fuel storage rack module design.

159 Pages Follow

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
3460 LEXINGTON AVE. NO., ST. PAUL, MINNESOTA 55112
AREA CODE 612 484-7261 TELEX #29-7473

July 1977

SECTION 5.3

MODEL DESCRIPTION, FORMULATION AND ASSUMPTIONS

FOR THE

SEISMIC ANALYSIS OF BWR SPENT FUEL RACKS

At

Duane Arnold

James FitzPatrick

Peach Bottom Units 2 & 3

Nuclear Power Plants

PaR Jobs: 3088, 3090, 3091

PREPARED BY ____________ DATE 7-14-77

APPROVED BY ____________ DATE 7-14-77

Revision No. 3 Date 3-27-78

REVISION RECORD

REV NO.	DATE	PAGES OR SECTIONS REVISED	APPRV'D	CHK'D BY	DATE
1	8/23/77	Gen. Revision	[illegible]		8/22/77
2	10/20/77	Revised Pges.3 & 6 and 6&7 of the Appendix	[illegible]	[illegible]	10/20/77
3	3-23-78	Revised page 5.3-12	[illegible]	[illegible]	3/27/78

SEISMIC MODEL DESCRIPTION, FORMULATION, AND ASSUMPTIONS

1.0 SCOPE

This document is intended to define the seismic analysis models descriptions, assumptions and formuations, for BWR Spent Fuel Racks.

A combination time history and static analysis will be done via computer solution programs ANSYS and SAP IV respectively. The following related items are covered specifically in this document.

I. ANSYS Time History Model

a. program documentation
b. model description
c. model assumptions
d. section property input
e. geometry input
f. mass input
g. damping input

II. SAP IV Static Modal

a. program documentation
b. model description
c. boundary conditions
d. load input description

2.0 ANSYS[1] MODEL FORMULATION

The rack structure consists of four side panels bolted top and bottom to a very stiff box grid. The corners of the side panels are riveted together via formed angles. The structural system may therefore be visualized as a large square or rectangular tube enveloped by the side panels with no structural stiffness added for either the poison cans or fuel assemblies. Dynamic analysis of a detailed SAP IV model have determined the first two natural frequencies to be orthogonal and simple cantilever modes at 8 HZ; and subsequent horizontal frequencies are greater than 28 HZ. A vertical diaphragming frequency of the bottom casting exists at 14 HZ.

The rack structure for the simplified dynamic model used in the ANSYS analysis is idealized as a planar frame consisting of a cantilever beam extending the height of the racks, attached to a horizontal beam at the base (bottom casting elevation) with leg beams connecting the ends of this member to the floor. (See Figure 2). Section properties 2-4 are calculated directly from the composite of the four side panels and bottom casting legs. Section 5 is located at the same elevation as Section 3 but is not attached to it. It represents the vertical diaphragming of the bottom casting. Fundamental frequencies of this idealized system agree quite closely with the detail model.

To consider the non-linear effects of module rocking and sliding and fuel rattling the ANSYS model is expanded and shown in Figure 3. Here a center pole Section 1 representing the mass and stiffness of all the fuel assemblies extends the height of the rack. It is pinned at the bottom of the rack and is allowed to impact at the top and top quarter point, nodes 1 and 2, and 3 and 4. A 3/8" gap on each side occurs at these points which represent the fuel assembly, can clearance. The section properties of the fuel channel are used for this element so that the highest overturning loads will result on the rack at all times as attributed to this stiffe: section. Also due to the stiffness of this member and based on past analysis, fuel-can impact below the top quarter is unlikely, such that the 3/8" gap at node 5 and 6 will not close. Note, also, that this model conservatively assumes that all fuel assemblies are in phase and move together at all times.

The vertical spring under each leg is known as an "interface element". The interface element represents two plane surfaces which may maintain or break physical contact and slide relative to each other. At each time step, the program compares the horizontal force in the interface element against the coefficient of friction to see if sliding will occur and also vertically releases the element, if tensile forces exist in the leg, allowing for uplift and rocking.

A single vertical degree of freedom represents the pool floor under the racks. Its mass is the total pool mass under the area of each rack. The spring rate of this mass is calculated to give the same frequency as the first mode diaphragm frequency of the combined spent fuel floor, water and racks. (Approximately 80 HZ)

A structural damping of 6% (SSE) shall be used for Iowa, 3% (SSE) and 2% (OBE) for FitzPatrick, and 5% (SSE) for Peach Bottom

All water entrapped within the rack envelope is added to the horizontal mass. Because the pool water moves with the pool walls at the rack elevation (i.e. no sloshing), water effects between the rack and the walls are ignored; therefore, conservatively assuming that the damping forces generated in "pumping" this confined water from the wall rack gap are much greater than any added external water mass effects due to flow pressure drop across the rack.

Figure 4 represents a two rack model.It includes all the effects of the single rack model plus the interaction or potential for banging with other racks in the pool. Gap springs are located at the top and bottom casting elevation and are initially closed. This model assumes that the largest interaction occurs for a pair of racks because their rocking motion away from each other is unconfined by adjacent modules.

The following summarizes the mass input on a per cavity basis.

Dry Module Mass	136#	Wet Module Weight	78#
Dry Fuel & Channel Mass	745#	Wet Fuel & Channel Weight	672#
Entrapped Water Mass	181#		
Total Horizontal Mass =	1062#/Cavity.	Total Wet Wt. =	750#/Cavity

Total vertical mass = 136 + 745 = 881#/Cavity

The masses are distributed to the model as shown in Figure 3 in the following manner:

a) Fuel mass density between nodes 2,4,6 and 8 in X direction only, $= (\text{No. Cavities}) \times (745\#) \ / \ell_1 (A_1) = \rho_1$, for Section 1.

b) Racks and water mass density between nodes 1,3,5 and 7 in X direction only $= (\text{No. Cavities}) \times (181 + 136) \ / \ell_2 (A_2) = \rho_2$, for Section 2.

c) Concentrated fuel mass at node 11 in Y direction only, $= (1/2 \text{ No. Cavities}) \times (745) = M_2$ for Section 5.

d) Concentrated masses at nodes 9 and 10 in Y direction only $= (1/2 \text{ No. Cavities}) \times (136) + (1/4 \text{ No. Cavities}) \times (745) = M_1$

e) Note gravity loading in the Y direction is equal to (750/881) times the total vertical mass.

Attached Tables I and II summarize the section properties, dimensions and mass of the various size modules.

The following free standing and rack conditions shall be analyzed.

1. .2 coefficient of friction full single rack
2. .2 coefficient of friction empty single rack
3. .8 coefficient of friction two full racks

Conditions 1 and 2 shall be analyzed to determine maximum displacement of the racks relative to the pool floor. In condition 2 for empty racks the ratio of total horizontal mass to vertical mass increases by approximately a factor of 2:1. Therefore, this condition will yield the largest displacement and will be used to qualify both conditions 1 and 2. This condition will be simulated in the computer analysis by using a full rack at .1 coefficient of friction. Condition 3 shall be analyzed to determine maximum rack loads for the SAP IV static analysis.

Simultaneous horizontal and vertical time histories are input at the floor spring location. These generated time histories correspond to a ± 15% broadened equipment sprectra at the spent fuel floor elevation.

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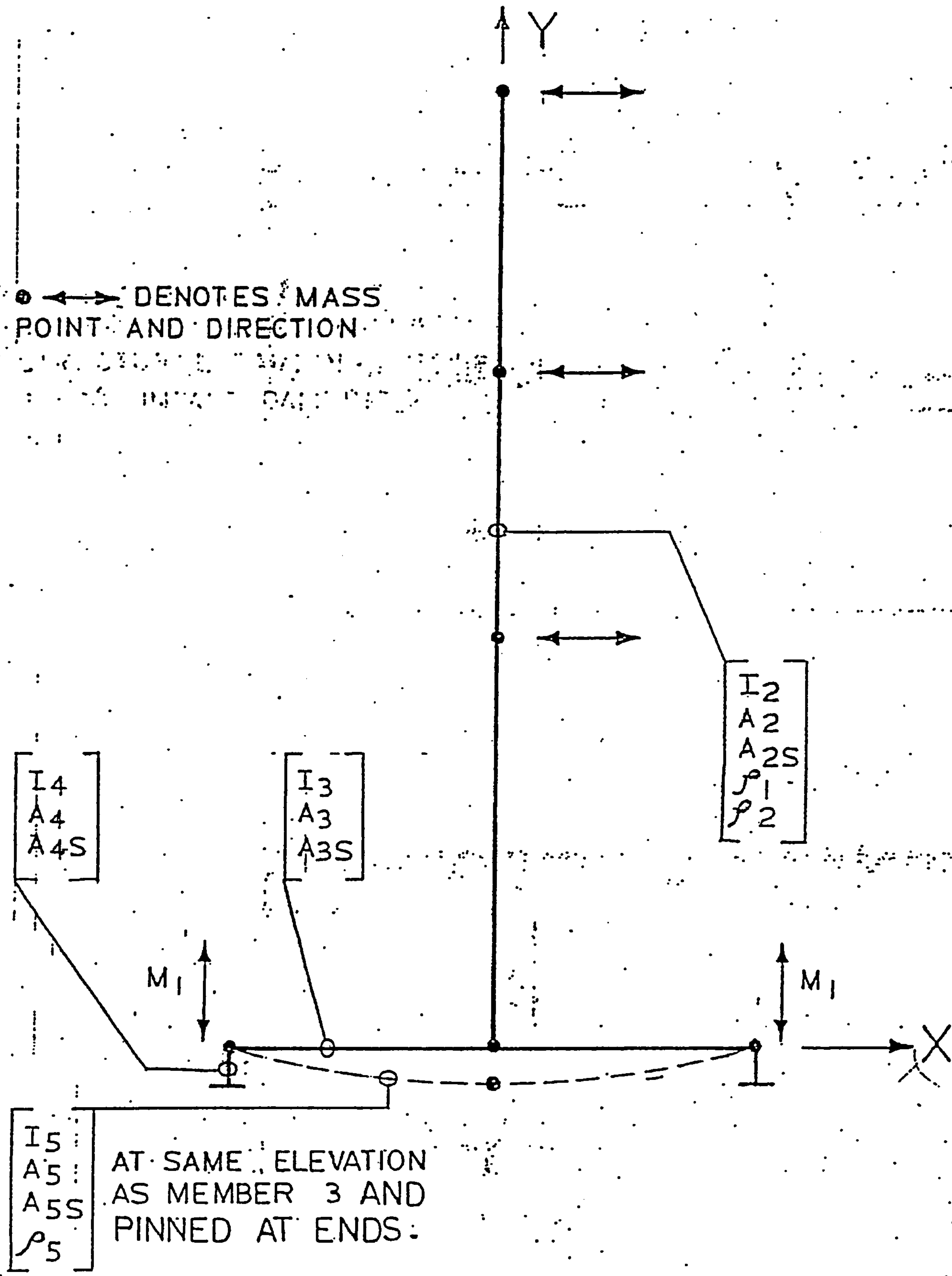
1) ANSYS, User Manual, Swanson Analysis Systems Inc. Elizabeth, Pennsylvania.

3.0 SAP IV FINITE ELEMENT MODEL

The computer program called SAP IV (public version) for static and dynamic analysis of linear structural systems is used to analyze the mathematical model. The development and documentation of SAP IV was sponsored by grants from the National Science Foundation and was authored by Klaus-Jurgan Bathe, Edward L. Eilson and Fred Peterson of the University of California, Berkeley, Calif. It is available as Report Number EERC 73-11 revised April 1974, from the Earthquake Engineering Research Center at the University of California. SAP IV has been installed on a Control Data Corporation Cyber 74 computer in Minneapolis, Minnesota where the model was analyzed.

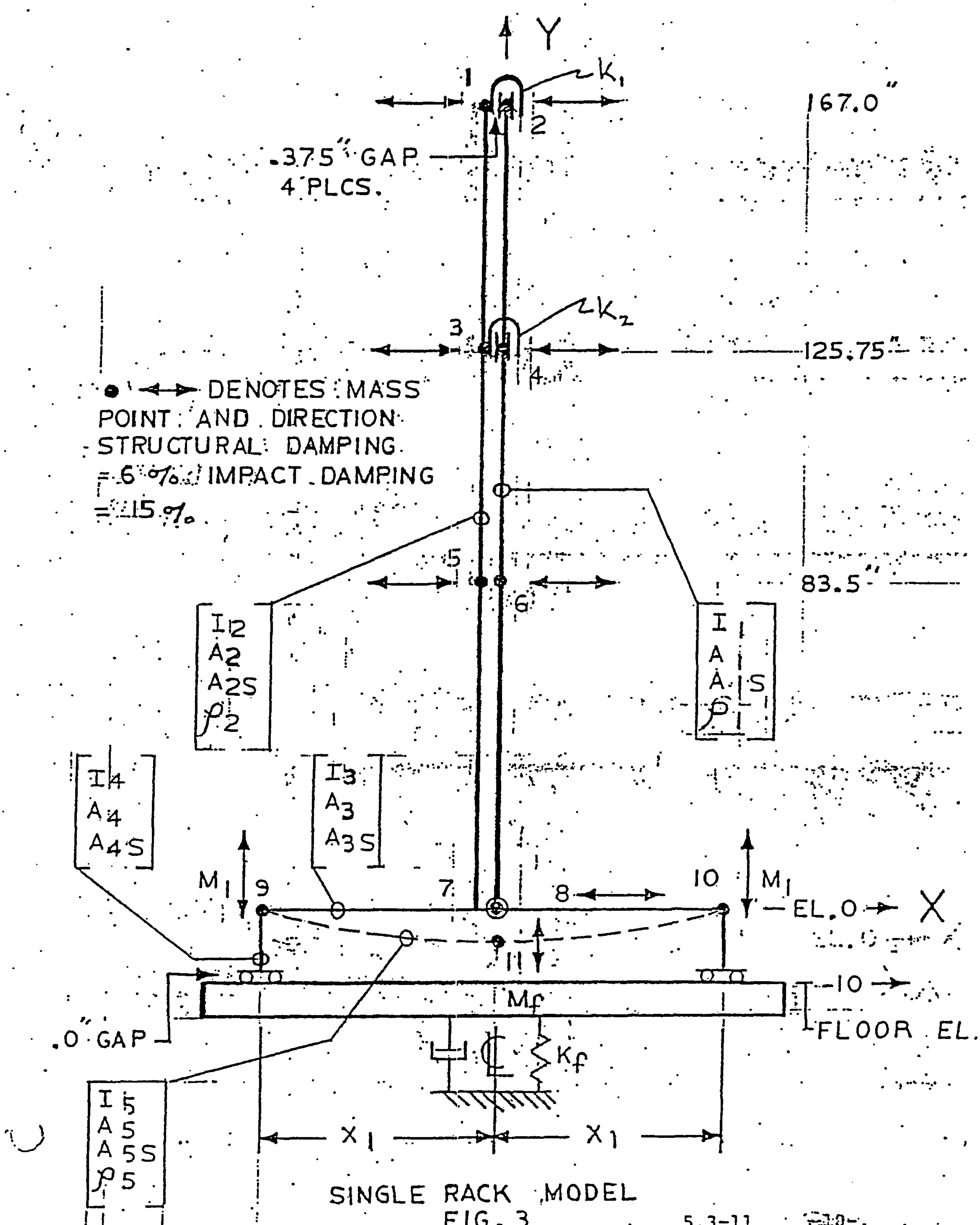
Figure 1 delineates the SAP IV computer model. The spent fuel rack is idealized as a three dimensional detailed finite element model of nodal points, consisting of over 400 flexural beam column elements representing the side plates and angle clips.

Only two of the module feet are fixed to ground. Reactions for the other two feet and nodal forces needed to put the rack in equilibrium are developed for worst load cases from the ANSYS time history analysis. These horizontal and vertical static forces are applied to the SAP IV model in the same as on the ANSYS model. An equal load set is applied in an orthogonal plane. An SRSS is computed for each of these two load sets for tabulated and compared against their allowables for each load case.



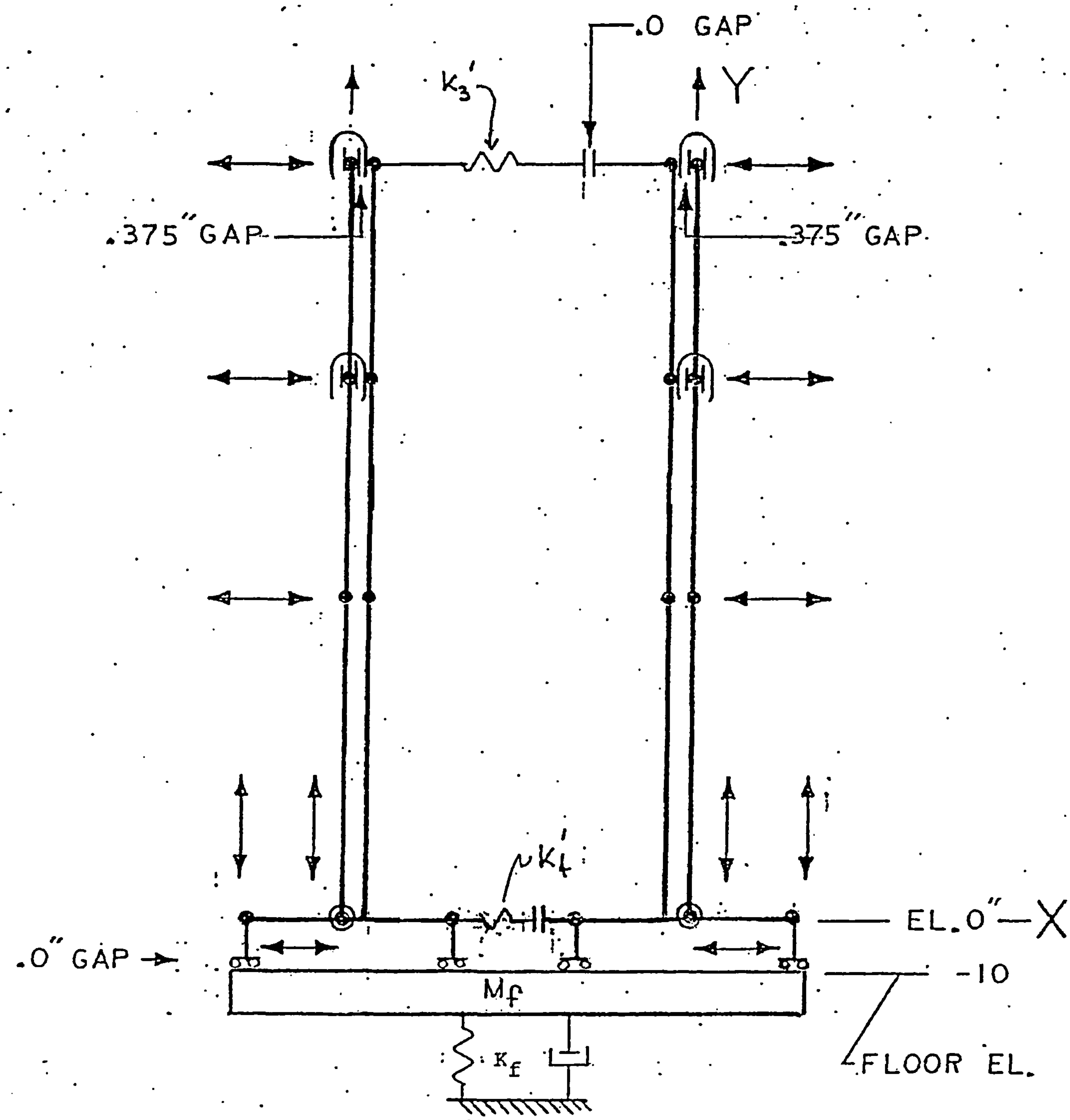
SINGLE RACK ATTACHED FUEL MODEL

FIG. 2



SINGLE RACK MODEL
FIG. 3

⊙ ←→ DENOTES MASS POINT AND DIRECTION
STRUCTURAL DAMPING = 6 %, IMPACT
DAMPING = 15 %



DOUBLE RACK MODLE

FIG. 4

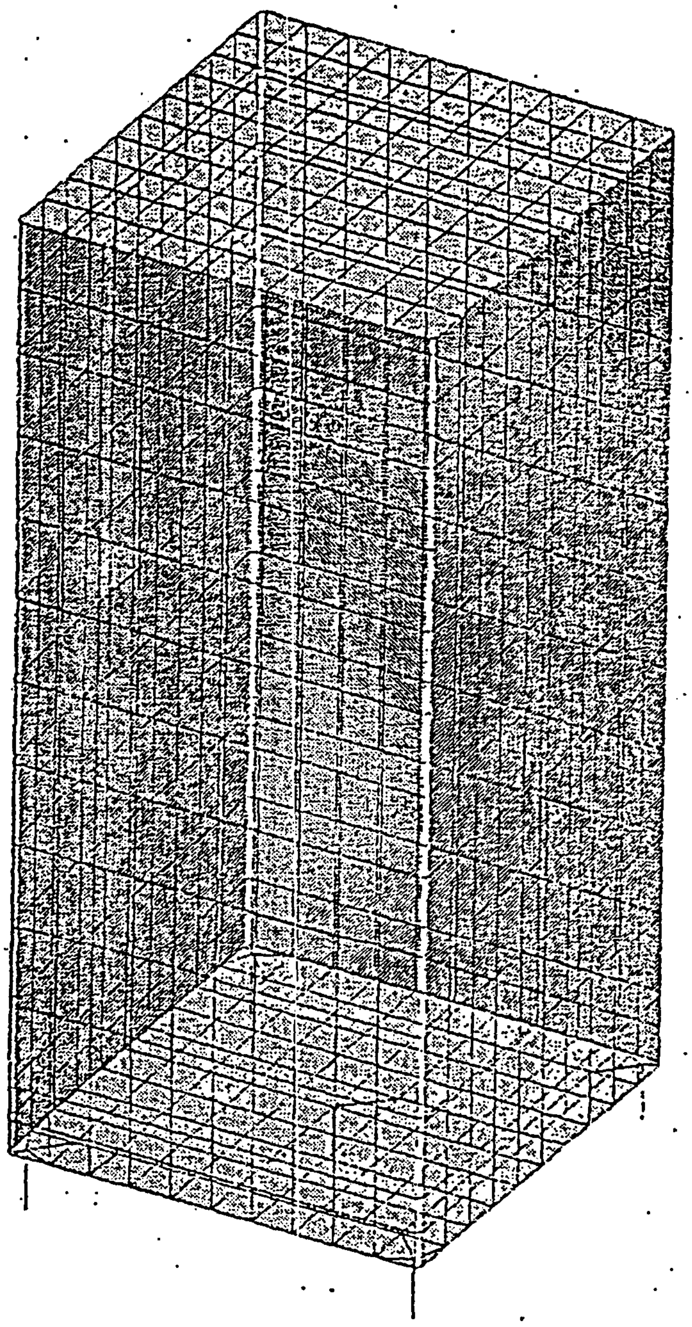


FIGURE 5.3.3-2
FINITE ELEMENT MODEL

Figure 1

TABLE I

MODULE SECTIONS PROPERTIES

Module Size	X_1 In	I_1 In 4	A_1 In 2	I_2	A_2 *	I_3	A_3 *	I_4	A_4 *	I_5	A_5 *
8 x 12	24.5"	1104	114.2	84070	140	388,000	167	280	38	201	162
9 x 12	28"	1242	128.5	108,200	147	388,000	167	280	38	245	171
8 x 11	23.2	1012	104.7	66,520	126	388,000	167	280	38	211	153
10 x 11	29.8	1265	130.9	109,200	139.5	388,000	167	280	38	327	171

* For shear area use 1/2 of total area except Section 3 use total area.

$E = 10.3\ (10^6)$ psi.

$G = 3.8\ (10^6)$ psi.

TABLE II

MODULE WEIGHT SUMMARY

Module Size	No. Cavity	Total dry fuel weight #	$A_1 \ell_1$ In^3	ρ_1 $\#/In^3$		M_2 #	Total Rack + Water	$A_2 \ell_2$ In^3	ρ_2 $\#/In^3$	M_1 #	Total Vertical Wt. #	Total Horizontal Wt. #
8 x 12	96	71520	19071.4	3.748		35760	30432	233380	1.301	24408	84580	101950
9 x 12	108	80460	21459.5	3.748		40230	34236	24549	1.395	27459	95148	114696
8 x 11	88	65560	17485	3.748		32780	27896	21042	1.326	22374	77525	93456
10 x 11	110	81950	21860.3	3.748		40975	34870	23297	1.497	27968	96915	116820

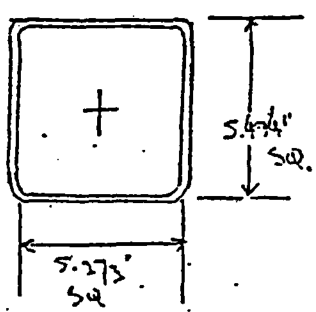
APPENDIX A

SECTION PROPERTY CALCULATIONS

BY .... DATE .... SUBJECT .... SHEET NO 1 OF ....

CHKD. BY .... DATE .... JOB NO ....

SECTION 1 FUEL CHANNEL REF. GE DRWG. 329E285



$A = (5.494)^2 - (5.273)^2 = 2.38 \text{ in}^2$

$I = [(5.494)^4 - (5.273)^4] / 12 = 11.5 \text{ in}^4$

$A_s = 2.38/2 = 1.19 \text{ in}^2$

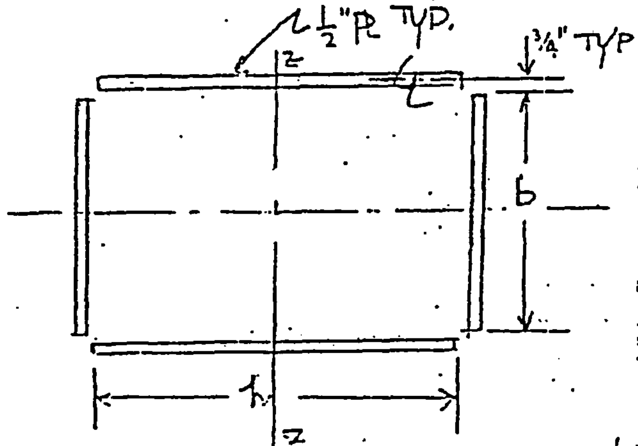
WEIGHT PER CAVITY = 745#

$l = 167"$

$\rho_1 = \text{No. CAV.} (745) / l \cdot A_1$

MODULE SIZE	I_T	TOTAL FUEL W_T	A_{total}	ρ_1
8×12	1104	71520#	114.24	3.748 #/in²
9×12	1242	80460	128.52	3.748
8×11	1012	65560	104.72	3.748
10×11	1265	81950	130.9	3.748

SECTION 2



$A = (2/2)b + (2/2)h$

$I_{zz} = 2(1/2)(h^3)/12 + 2(1/2)b(h/2 + .75)^2$

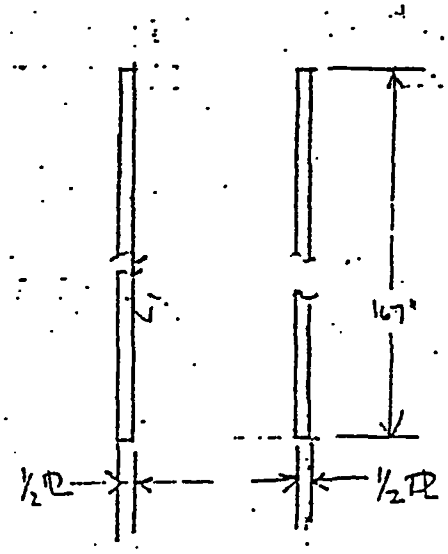
$= h^3/12 + b(h/2 + .75)^2$

$l = 167"$

DIV.	MODULE SIZE	b	h	A	(1")h³/12	(1")× b(h/2+.75)²	I_{zz}	total RACK + WATER	ρ_2
7"c/c	8×12	84	56	140	14634	69431	84070	30432	1.301
	9×12	84	63	147	20837	87365	108,200	34236	1.395
6 5/8 c/c	8×11	72.88	53	125.88	12406	54114	66520	27896	1.327
	10×11	72.88	66.625	139.5	24645	84553.2	109,200	34870	1.496

BY ..... DATE ..... SUBJECT ..... SHEET NO. 2 OF .....
CHKD. BY ..... DATE 10/17/77 ..... JOB NO. .....

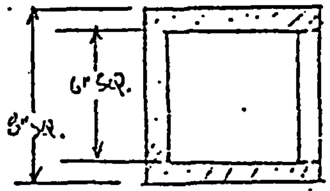
SECTION 3



$A = 2(1/2)\,167" = 167\ in^2$

$I = bh^3/12 = (2)\tfrac{1}{2}(167)^3/12 = \underline{388{,}122\ in^4}$

SECTION 4



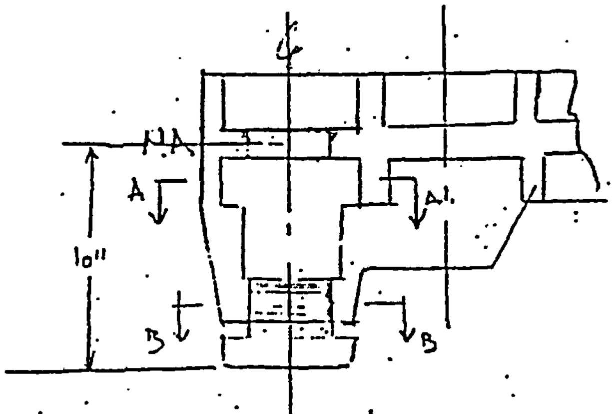
SECTION A-A

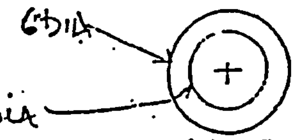
$A = (8^2 - 6^2) - 1(6) = 22\ in^2$

FOR TWO LEGS $A' = 44\ in^2$

$I = (8^4 - 6^4)/12 = 233\ in^4$

FOR TWO LEGS, $I' = 466\ in^4$





SECTION B-B

$A = .785\,(6^2 - 4^2) = 15.7\ in^2$

$I = \pi/64\,(6^4 - 4^4) = 51.\ in^4$

FOR 2 LEGS $A' = 31.4\ in^2$

FOR 2 LEGS $I' = 102\ in^4$

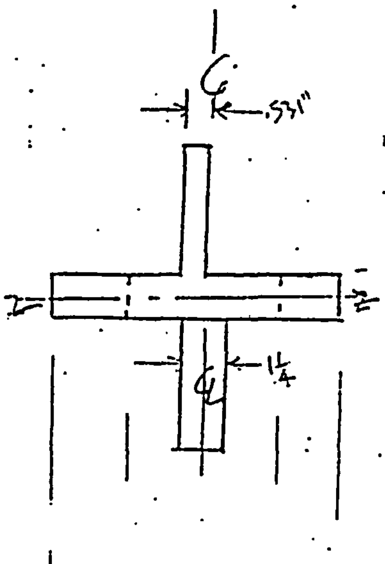
AVERAGE FOR TWO LEGS.

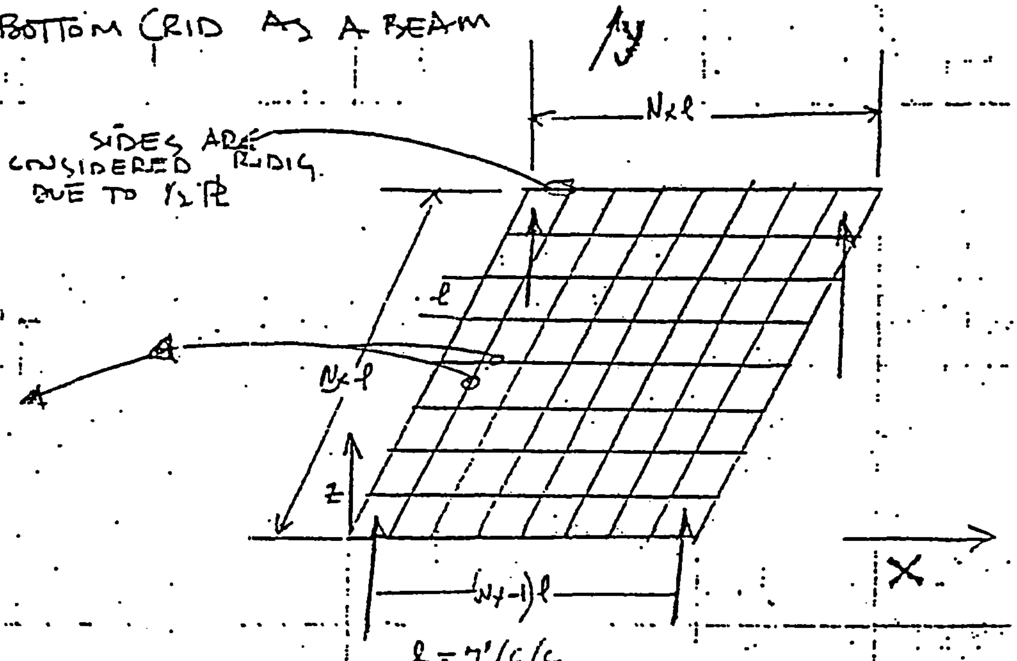
$A_{AVG} = (44 + 31.4)/2 = \underline{37.7\ in^2}$

$I_{AVG} = (466 + 102)/2 = \underline{284\ in^4}$

SECTION 5

CONSIDER THE BOTTOM GRID AS A BEAM SYSTEM.





$\ell = 7"/c/c$

TYPICAL BOTTOM GRID

TYPICAL SECTION

DESIGN - A = 9 in²

DESIGN - $I_{ZZ\,AVG} = 20\ in^4$

THE TOTAL VERTICAL (Z) STIFFNESS CAN BE IDEALIZED AS GROUPS OF ORTHOGONAL UNIFORMLY LOADED SIMPLE BEAMS.

TOTAL SPRING RATE "K_T" $= \dfrac{384EI}{5\ell^3}\left[\dfrac{N_y-1}{(N_x-1)^2} + \dfrac{N_y-1}{(N_y-1)^2}\right]$

$$= \frac{384EI}{5\ell^3}\left[\frac{1}{(N_x-1)^2} + \frac{1}{(N_y-1)^2}\right] = \frac{384EI}{5\ell^3}\left[\frac{(N_x-1)^2+(N_y-1)^2}{(N_x-1)^2(N_y-1)^2}\right]$$

FOR LOADING USE FUEL U.L. 745#

$\therefore \Delta = 745\, N_x N_y / K_T$

$$\Delta = \frac{745^{\#} N_x N_y}{384\, EI}\; 5\ell^3\; \frac{(N_x-1)^2(N_y-1)^2}{(N_x-1)^2+(N_y-1)^2}$$

$E = 10.3(10)^6$

$$\Delta_{7"c/c} = 1.61(10)^{-5}\, N_x N_y \frac{(N_x-1)^2(N_y-1)^2}{(N_y-1)^2+(N_y-1)^2} \qquad \ell = 7",\ I = 20\ in^4$$

$$\Delta_{6\,5/8\ c/c} = 1.36(10)^{-5}\, N_x N_y \frac{(N_x-1)^2(N_y-1)^2}{(N_x-1)^2+(N_y-1)^2} \qquad \ell = 6\,5/8"\ c/c$$

BY ______ DATE ______ SUBJECT ______ SHEET NO. 4 OF ______
CHKD. BY ______ DATE ______ JOB NO. ______

SECTION 5 cont'd

8×12 MODULE 7" c/c $N_x = 8$, $N_y = 12$

$\Delta = 1.64(10^{-5})\,\dfrac{8(12)\;7^2(11)^2}{(7^2+11^2)} = .053''$ (MID SPAN DEFLECTION)

I_{eff} (in 8 Direction) $= \dfrac{5(745)\,8(12)\,(8-1)^3(7)^3}{384\;10.3(10)^6\,(.053)} = 201\ in^4$ $l = (8-1)7 = 49''$

$f_N = \dfrac{n^2\pi^2}{2\pi l^2}\sqrt{\dfrac{EI}{m}} = \dfrac{(1)\pi}{2(49)^2}\sqrt{\dfrac{10.3(10^6)\,201}{56(745)/386(49)}} = \underline{15.3\ Hz}$ (simple Beam)

$A_z = [(N_x-1)+(N_y-1)]\,9 = \underline{162\ in^2}$

9×12 MODULE 7" c/c $N_x = 9$, $N_y = 12$

$\Delta = 1.64(10)^{-5}\,9(12)\;8^2(11)^2/(8^2+11^2) = .072''$

I_{eff} (9 DIR) $= \dfrac{5(745)\,9(12)\,(9-1)^3\,7^3}{384\;10.3(10)^6\,(.0723)} = \underline{245\ in^4}$ $l = (9-1)7 = 56''$

$f_N = [\pi/2(56)^2]\sqrt{\dfrac{10.3(10)^6\,245}{108(745)/56(386)}} = \underline{13.0\ Hz}$

$A_z = [(9-1)+(12-1)](9) = 171\ in^2$

8×11 MODULE 6 5/8" c/c $N_x = 8$, $N_y = 11$

$\Delta = 1.34(10^{-5})\,8(11)\;7^2(10^2)/(7^2+10^2) = .039$

I_{eff} (8 DIR) $= \dfrac{5(745)\,8(11)\,(8-1)^3(6.625)^3}{384\;10.3(10^6)\,(.039)} = \underline{211\ in^4}$ $l = 7 \times 6.625 = 46\,3/8$

$f_N = \dfrac{\pi}{2\cdot 7^2(6.625)}\sqrt{\dfrac{10.3\,(211)\,10^6}{88(745)/386\,(46.375)}} = \underline{17.7\ Hz}$

$A_z = [8-1+11-1](9) = \underline{153\ in^2}$

10×11 MODULE 6 5/8" c/c $N_x = 10$, $N_y = 11$

$\Delta = 1.34(10^{-5})\cdot 10(11)\;9^2(10)^2/(9^2+10^2) = .067''$

I_{eff} (10 DIR) $= \dfrac{5\;745(10)11\;(10-1)^3(6.625)^3}{384\;10.3(10^6)\;.067} = \underline{327\ in^4}$ $l = 6.625 \times 9 = 59.625$

$f_N = \dfrac{\pi}{2(59.625)^2}\sqrt{\dfrac{10.3(10^6)\,327}{110(300)/386(59.625)}} = \underline{13.5\ Hz}$

$A_z = [(10-1)+(11-1)]9 = \underline{171\ in^2}$

CHKD. BY [illegible] DATE 10/13/77 SUBJECT JOB NO.

FLOOR STIFFNESS

$E_c = 3.8(10)^6$ psi (concrete)
$\nu = .17$

$D = Et^3/12(1-\nu^2)$ See Roark Table 36 page 577 5th Edition
$= 3.76(10^5)\,t^3$

$f = \frac{K_n}{2\pi}\sqrt{\frac{Dg}{wa^4}}$ See case No 15 & 16 Roark page 579 Natural frequency of Rectangular uniformly load plate where K_1 = fixed edges eq 15, K_2 = simply supported eq 16

"W_W" uniform water load = 38'(1) 62.2 / 144 = 16.4 psi
"W_C" uniform concrete weight = 144#/ft³ (t)/1728 = t"/12 psi
"W_R" uniform rack & fuel load = "No cavities" (750)# / Area of floor

Plant	a	b	total Area	t	a/b	D	fixed K_1	simply K_2	No. cavities	W_R	W_F	W_W	W_T
Iowa	240	480	115200	72	.5	1.2(10)¹¹	24	12	2069	13.47	6.0	16.4	35.8 psi
FitzPatrick	372	480	178560	60	.77	.7(10)¹¹	29	16	2244	9.42	5.0	16.4	30.8 psi
Peach Bottom	424	480	203520	75"	.88	1.3(10)¹¹	30	17	2574	9.48	6.25	16.4	32.14 psi

Iowa (Fixed) $f_n = 24/6.28\sqrt{1.2(10)^{11}\,386/35.8(240)^4} = 75$ Hz
f (simply supported) = $f_n = 12/24(75) = 37$ Hz
f_{avg} = 56 Hz

FitzPatrick (Fixed) $f_n = 29/6.28\sqrt{.7(10)^{11}\,386/30.8(372)^4} = 31$ Hz
(simply supported) $f_n = 16/29(31) = 17.1$ Hz
f_{avg} = 24 Hz

Peach Bottom (Fixed) $f_n = 30/6.28\sqrt{1.3(10)^{11}(386)/32.1\,(424)^4} = 33$ Hz
(simply supported) $f_n = 17/30(33) = 18.7$ Hz
$f(avg)$ = 26 Hz

BY .... DATE .... SUBJECT .... SHEET NO. 6 OF ....
CHKD. BY .... DATE 11/10/77 JOB NO. ....

FLOOR STIFFNESS cont'd

$\omega_n = 2\pi f_n$

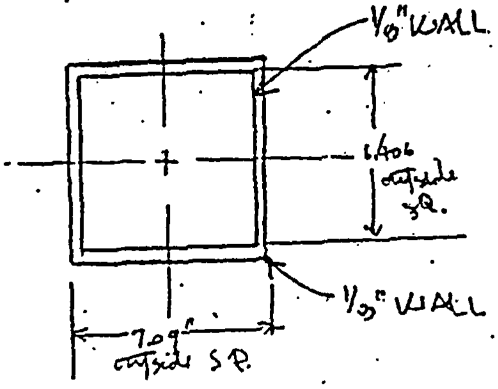
FOR IOWA use $f_n = 56$ Hz $\omega_n = 351$
PEACH BOTTOM use $f_n = 30$ Hz $\omega_n = 188.4$
FITZPATRICK use $f_n = 28$ Hz : $\omega_n = 176$

	MODULE SIZE	AREA	$W_E + W_W$	W_{EW}	W_R No. CAVITIES $\times 750^{\#}$	W_T	m_T	$f_{2\pi}$	K_E #/in
IOWA	8×11	4235 in² ✓	22.4 psi	94877	66000	160878	416.7	351	$5.15(10)^7$
	10×11	5257 in² ✓	22.4	117779	82500	200279	518.3	351	$6.4(10)^7$
PEACH BOTTOM	8×12	5061 in² ✓	22.4	113369	72000	185369	480	188.4	$1.7(10)^7$
	9×12	5661.5	22.65	128233	81000	209233	542	188.4	$1.92(10)^7$
FITZPATRICK	8×11	4235	21.4	90629	66000	156629	405.7	176	$1.25(10)^7$
	10×11	5257	21.4	112,500	82500	195000	505.1	176	$1.56(10)^7$

BY .... DATE 7/11/77   SUBJECT ....   SHEET NO. 7 OF ....
CHKD. BY .... DATE 10/13/77   JOB NO. ....

CAVITY STIFFNESS K_2

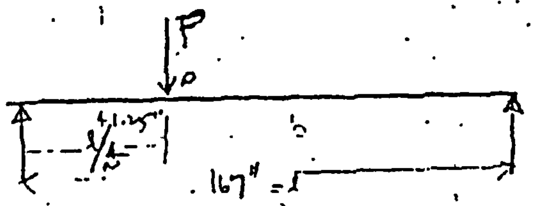
IMPACT SPRING @ nodes 3 & 4 is bending stiffness of cavity.



$A = 4(7.09)\,1/8 + 4(6.406)\,.125 =$

$I = (7.09^4 - 6.84^4)/12 + (6.406^4 - 6.156^4)/12 = \underline{48.8}$

$E = 10.3\,(10^6)$ psi



$a = l/4$

$b = 3/4\, l$

$\Delta = Pa^2 b^2 / 3EIl = P\,.25^2 l^2\,.75^2 l^2 / 3EIl$

$= 9 l^3 / 3(16)(16)\,EI =$

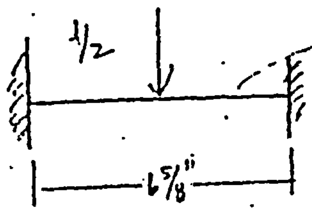
$\Delta = 3Pl^3/256\,EI \quad \therefore \quad K' = \frac{P}{\Delta} = 256\,EI/3l^3 = 9240$ #/in

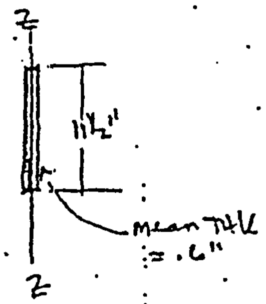
$K_2 = (\text{No. CAVITIES})/2\,(9240)$ #/in

	No. cavities	K_2
8×12	48	443,520 #/in
9×12	54	498,960 #/in
8×11	44	406,560
10×11	55	508,200

TOP GRID STIFFNESS K_1

IMPACT SPRING AT TOP NODES 1 & 2 IS BENDING STIFFNESS OF GRID CAVITY.





$E = 10.3(10^6)$ psi

$I_z = .6^3(11\tfrac{1}{2})/12$

$= .207$

$\Delta = Pl^3/192\,EI$

$K_{\text{Fixed}} = 192\,EI/l^3 = 1.4(10)^6$ #/in

$K_{\text{simply supported}} = 48/192\,(1.4)10^6 = 3.5(10^5)$

$K_{AVG} = .875(10^6)$ #/in

$K_1 = \text{No. Cavities}\,(.875)10^6$ #/in

	No. CAV.	$K_1\,(10^6)$
8×12	96	84
9×12	108	94.5
8×11	88	77
10×11	110	96.25

CHKD. BY HR DATE 10/19/77 SUBJECT JOB NO.

TOP CASTING SPRING RATE "K_3"

BOTTOM CASTING SPRING RATE "K_4" $E = 10.3 \times 10^6$ psi.

FOR TOP CASTING AVERAGE AXIAL AREA PER ROW $= 6 in^2 = A_T$
FOR BOTTOM ~~CASTING~~ AVERAGE AXIAL AREA PER ROW $= 9 in^2 = A_B$

MODULE	N	A_T	total A_T	length "l" $= 2 \times 1$	$K_3 = AE/l$ #/in	A_B	total A_B	$K_4 = AE/l$
8×12	12	6	72	49	$1.5(10)^7$	9	108	$2.2(10)^7$
9×12	12	6	72	56	$1.3(10)^7$	9	108	$1.9(10)^7$
8×11	11	6	66	46.4	$1.5(10)^7$	9	99	$2.2(10)^7$
10×11	11	6	66	59.6	$1.1(10)^7$	9	99	$1.72(10)^7$

SERIES SPRING RATE K_3' & K_4'

8×12 & 9×12 $\quad K_3' = \dfrac{1}{1/1.5 + 1/1.3}(10^7) = 7.0(10)^6$ #/in

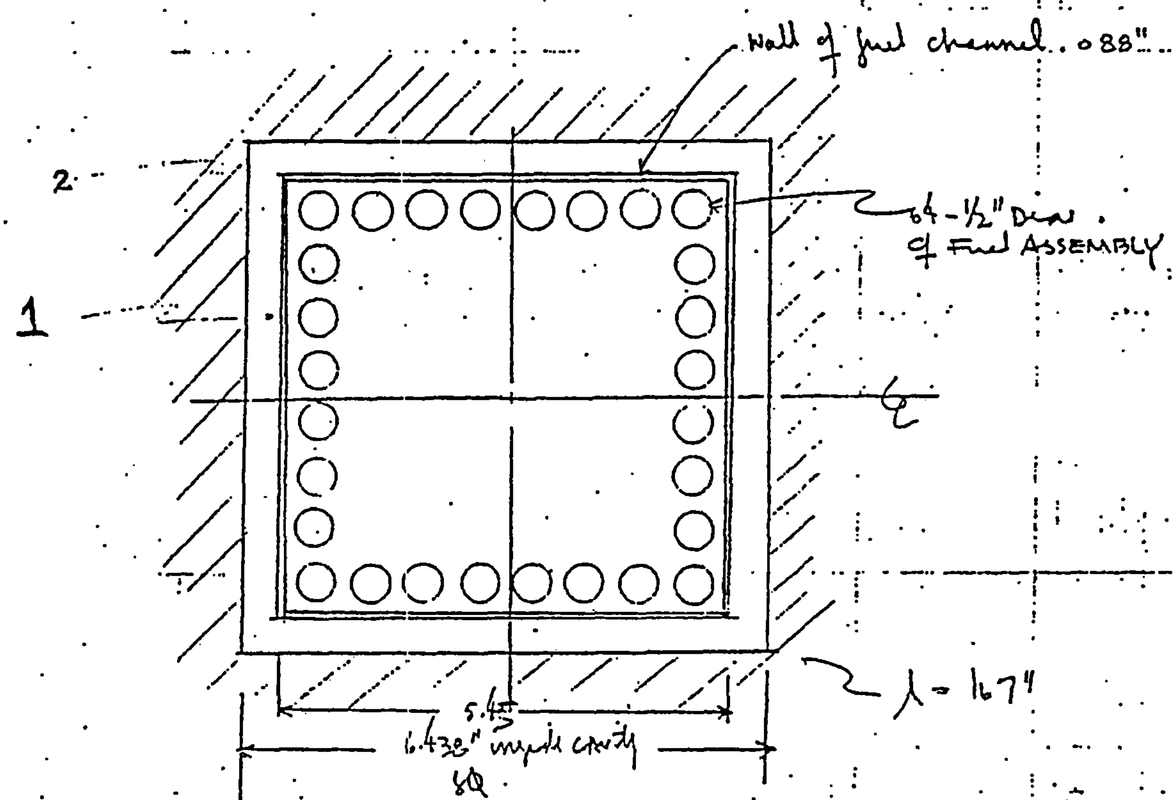
$$K_4' = \frac{1}{1/2.2 + 1/1.9}(10)^7 = 1.0(10)^7 \text{ #/in}$$

8×11 & 10×11 $\quad K_3' = \dfrac{1}{1/1.5 + 1/1.1}(10^7) = 6.0(10)^6$ #/in

$$K_4' = \frac{1}{1/2.2 + 1/1.7} = 1.0(10)^7 \text{ #/in}$$

BY ...... DATE	SUBJECT	SHEET NO. 7 OF ......
CHKD. BY NH DATE 10/19/77		JOB NO. ......

FUEL BUNDLE - CAVITY



total AREA inside CAVITY = $(6.438)^2 = 41.44\ in^2$
total AREA inside fuel channel = $(5.45)^2 = 29.7\ in^2$
total AREA of fuel pins = $64(\pi/4)(1/2)^2 = 12.56\ in^2$
Total AREA of channel = $[4(5.45)\ .088] = 1.918\ in^2$

Water displ'd by fuel pins = $[12.56\ (167')\ /1728]\ 62.2 = 75.5^{\#}$

water displ'd by fuel pins + channel = $[(1.918 + 12.56)(167)/1728]\ 62.2 = 87^{\#}$

Total fluid inside cavity = $[41.44(167)/1728]\ 62.2 = 249^{\#}$

TRAPPED WATER INSIDE CAVITY FUEL BUNDLE ONLY = $249 - 75.5 = 173^{\#}$

TRAPPED H_2O FUEL & CHANNEL = $249 - 87 = 162^{\#}$

5.4 TIME HISTORY SEISMIC ANALYSIS

DYNAMIC TIME HISTORY ANALYSIS OF SPENT FUEL RACKS

DUANE ARNOLD

PREPARED FOR:

PaR Systems Corp.
3460 Lexington Avenue North
St. Paul, Minnesota 55112

P. O. No. 22269-3 Rev. 2

December , 1977

PREPARED BY:

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L. A. Bergman

APPROVED BY: J. D. Stevenson

REVIEWED BY: A. J. Sturm
Engineering Proj. Manager
PaR Systems Corp.

REVISION RECORD

Revision Number	Date	Description	Changed By	Approved By	Date
1	1/12/78	Signatures on title page; Symbols defined; Revision levels of two computer programs defined; Changed Node 107 to 105 on Figure 35; Figure 41 changed to 42; Figure 4 left blank; Table of Contents added; Notation page added	LAB	DJK	1/12/78
2	3-27-78	Revised page 5-4-15			3/27/78

NOTATION

ξ - Percent of critical damping; dimensionless

ω - Circular frequency ($=2\pi f$); radians/second

K_{ij} - Stiffness coefficient; pounds/inch

C_{ij} - Damping coefficient; pounds - second/inch.

F_D - Damping force; pounds

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this report is to evaluate the performance of spent fuel racks under earthquake excitation. The particular module sizes examined are 8 x 11 and 10 x 11 for the Duane Arnold Plant and 8 x 12 and 9 x 12 for the Peach Bottom Plant.

Two types of analyses were performed. A single rack (as shown in Figure 1) analysis was done at a coefficient of friction, against rack sliding, of 0.1 to determine peak displacements. This was done for the 8 x 11 and 8 x 12 modules. The second type was a double rack analysis for the model of Figure 2, at a coefficient of friction against rack sliding of 0.8 to determine nodal forces for later application to a more detailed static model.

In both types of analyses, interaction between the fuel bundle and the cavity was allowed for by the use of gap elements (1). Interface elements (1) allowed the racks to slide--and/or rock. In the double rack analysis gap elements were also employed to simulate impact between the racks.

Details of these analyses and results will be presented in the body of this report.

2.0 DIGITIZED TIME HISTORIES

Plots of the artificial time history SSE response spectrums compared to Iowa Specification M-303 broaden response spectrums is shown in Figures A and B.. The artificial time histories are generic and were generated by JDS. The digitized time history was generated artificially utilizing computer program, SIMQKE[3] developed under the auspices of the National Science Foundation (4).

The horizontal artificial response spectrum not only completely envelopes Iowa Specification response spectrum but in range of structural periods of greatest interest .5 -0 seconds (frequency 2-∞hz.) accelerations are at least 100% greater. The artificial vertical response envelopes specification response spectrum everywhere except for periods of .25 to .33 seconds (4-3 hz.) where it is .12% lower for the damping. Since the vertical natural frequency of the structure is approximately .07 seconds (14 hz.) this perturbation is not significant. In fact the artificial response spectrum acceleration for structural periods from .6-0 seconds (6-∞ hz.) is 120-180% higher than the specification response spectrum.

The SIMQKE algorithm is as follows:

-- A power spectral density (P.S.D.) function is derived from the target floor response spectrum.

-- Fourier coefficients of sinusoidal components are derived from the P.S.D. at a predetermined frequency interval.

-- Phasing between the sinusoidal components are developed from a random number generator.

-- The components are summed in time and an artificial record developed.

-- A response spectrum is generated and compared with the target at 10 predetermined frequencies.

-- Iterate until convergence at the 10 frequencies is achieved, by scaling the fourier coefficients in proportion to the error.

The generated time histories have a duration of 15 seconds, digitized at an interval of .01 seconds. They are shown in Figures C and D, and the digitized records are appendicized in the back of this Section.

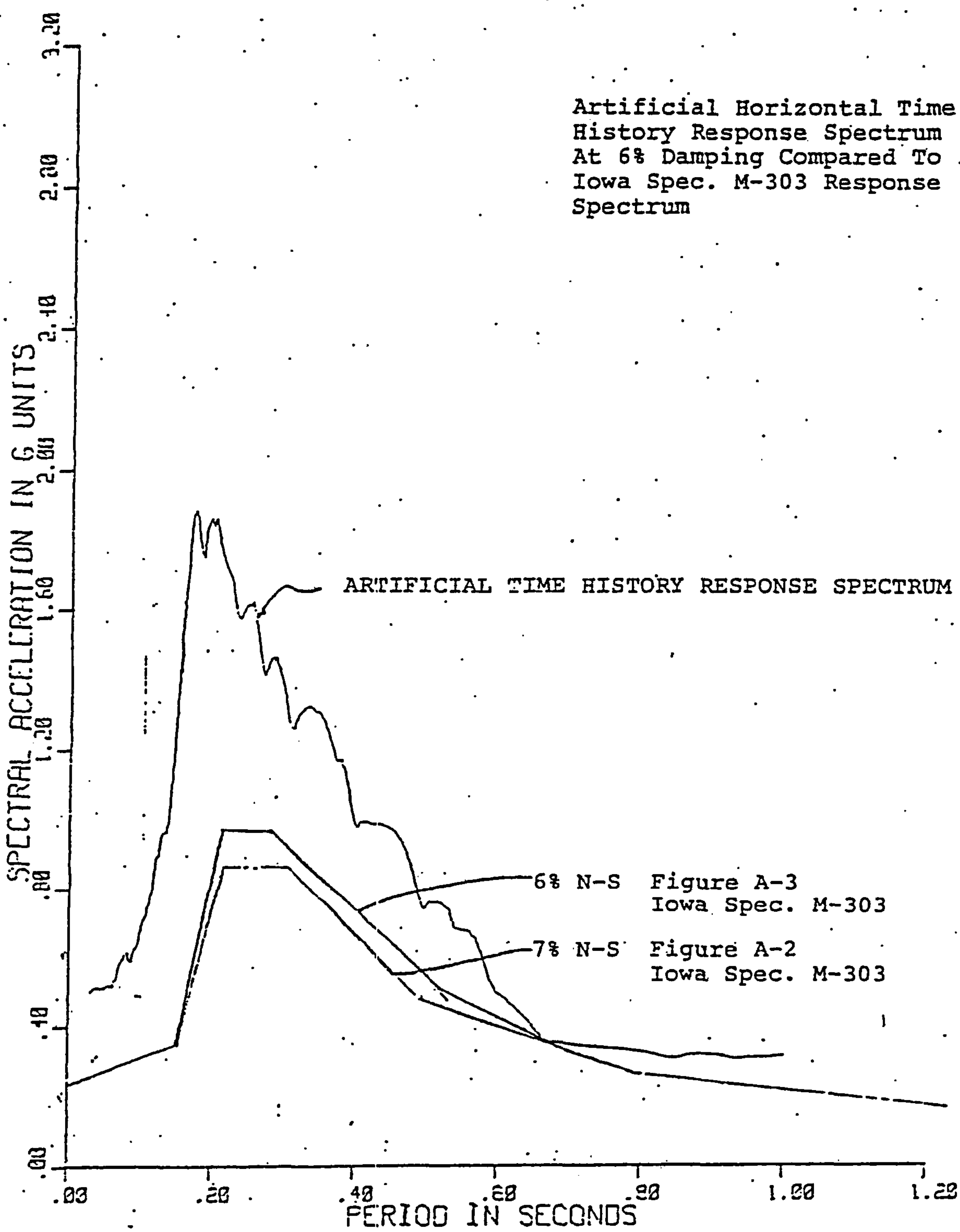

Artificial Horizontal Time History Response Spectrum At 6% Damping Compared To Iowa Spec. M-303 Response Spectrum
ARTIFICIAL TIME HISTORY RESPONSE SPECTRUM
6% N-S Figure A-3 Iowa Spec. M-303
7% N-S Figure A-2 Iowa Spec. M-303
SPECTRAL ACCELERATION IN G UNITS
PERIOD IN SECONDS
.00
.20
.40
.60
.80
1.00
1.20
.40
.80
1.20
1.60
2.00
2.40
2.80
3.20

FIGURE A

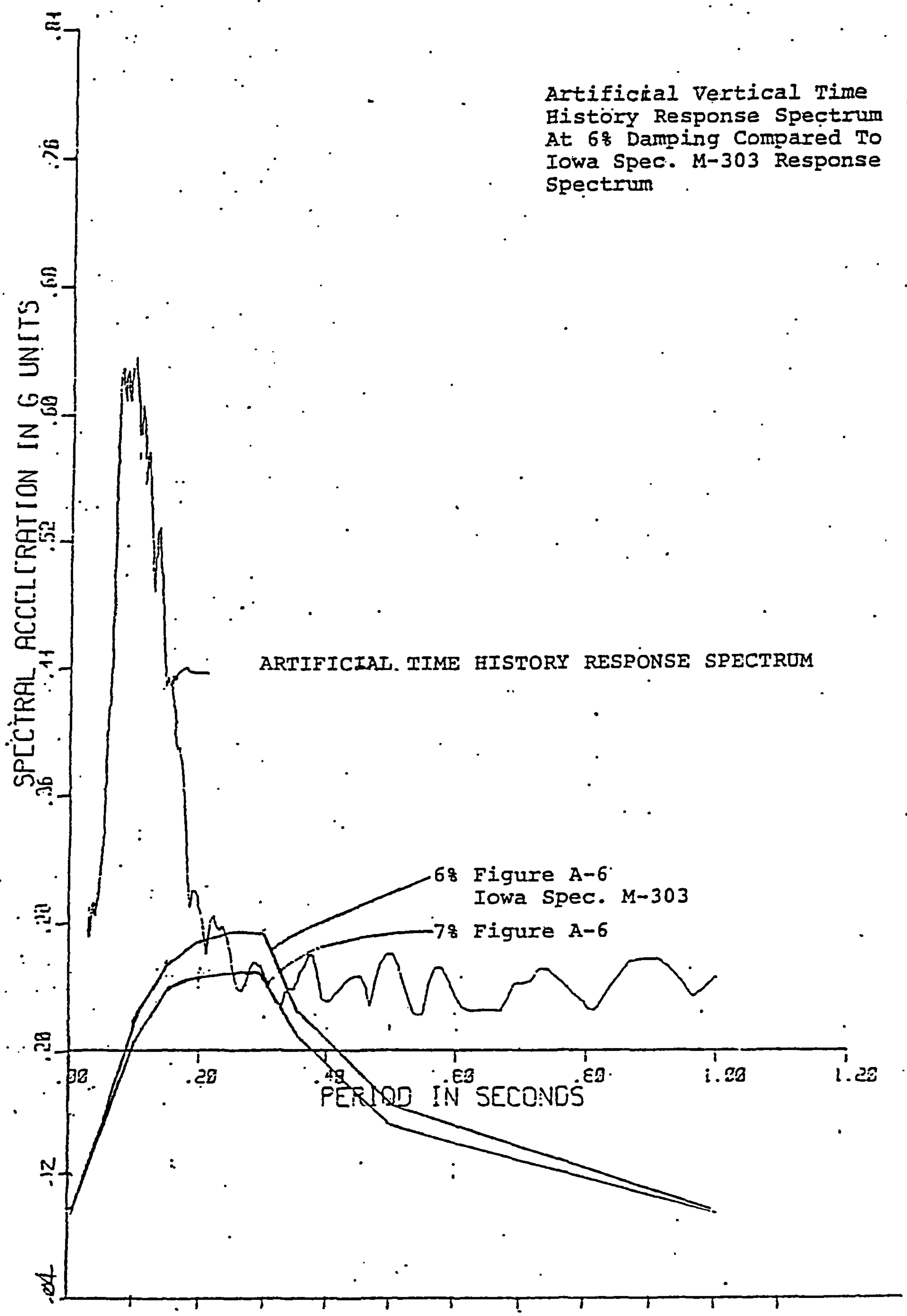

Artificial Vertical Time History Response Spectrum At 6% Damping Compared To Iowa Spec. M-303 Response Spectrum
ARTIFICIAL TIME HISTORY RESPONSE SPECTRUM
6% Figure A-6 Iowa Spec. M-303
7% Figure A-6
SPECTRAL ACCELERATION IN G UNITS
PERIOD IN SECONDS
.00
.20
.40
.60
.80
1.00
1.20

FIGURE B

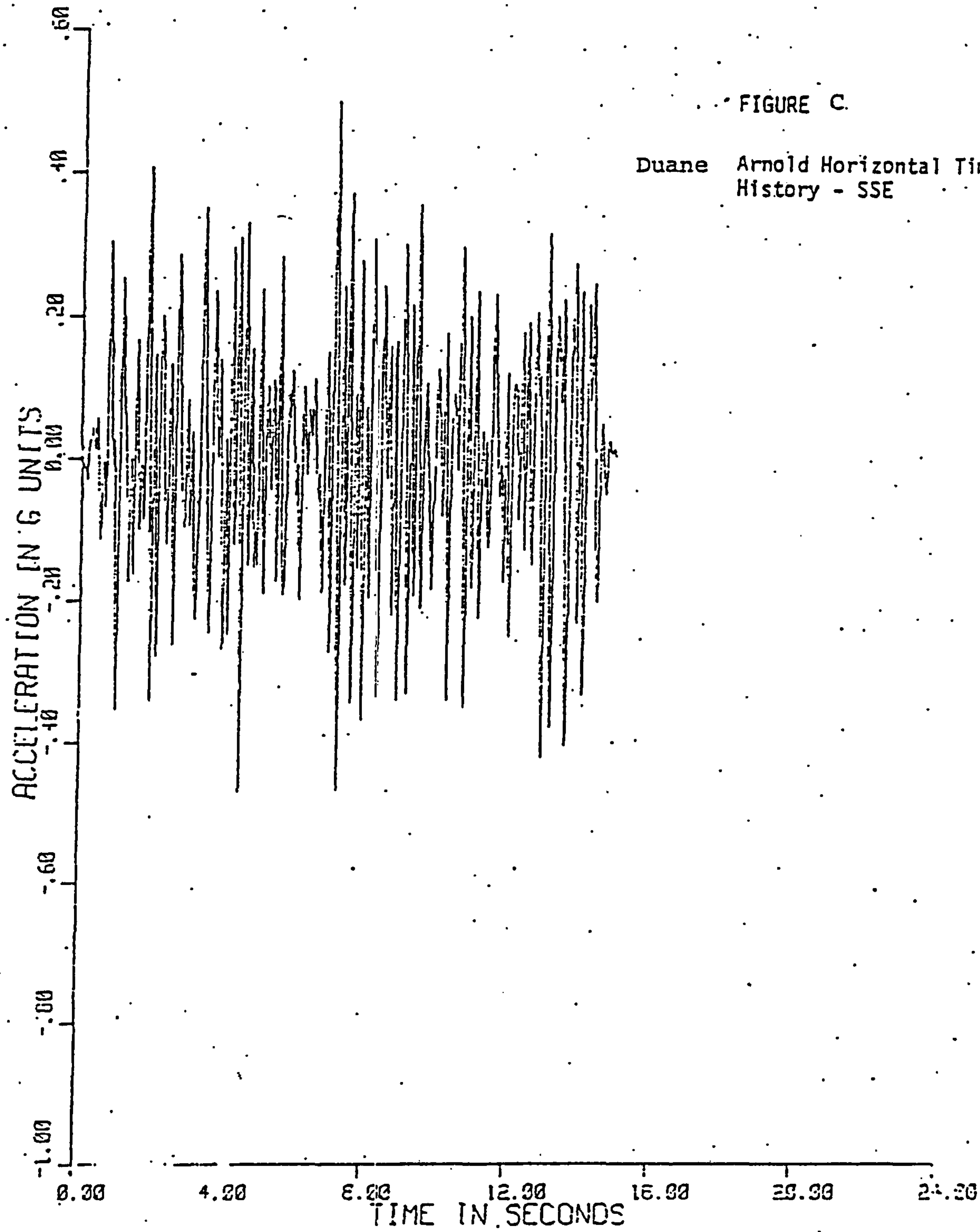
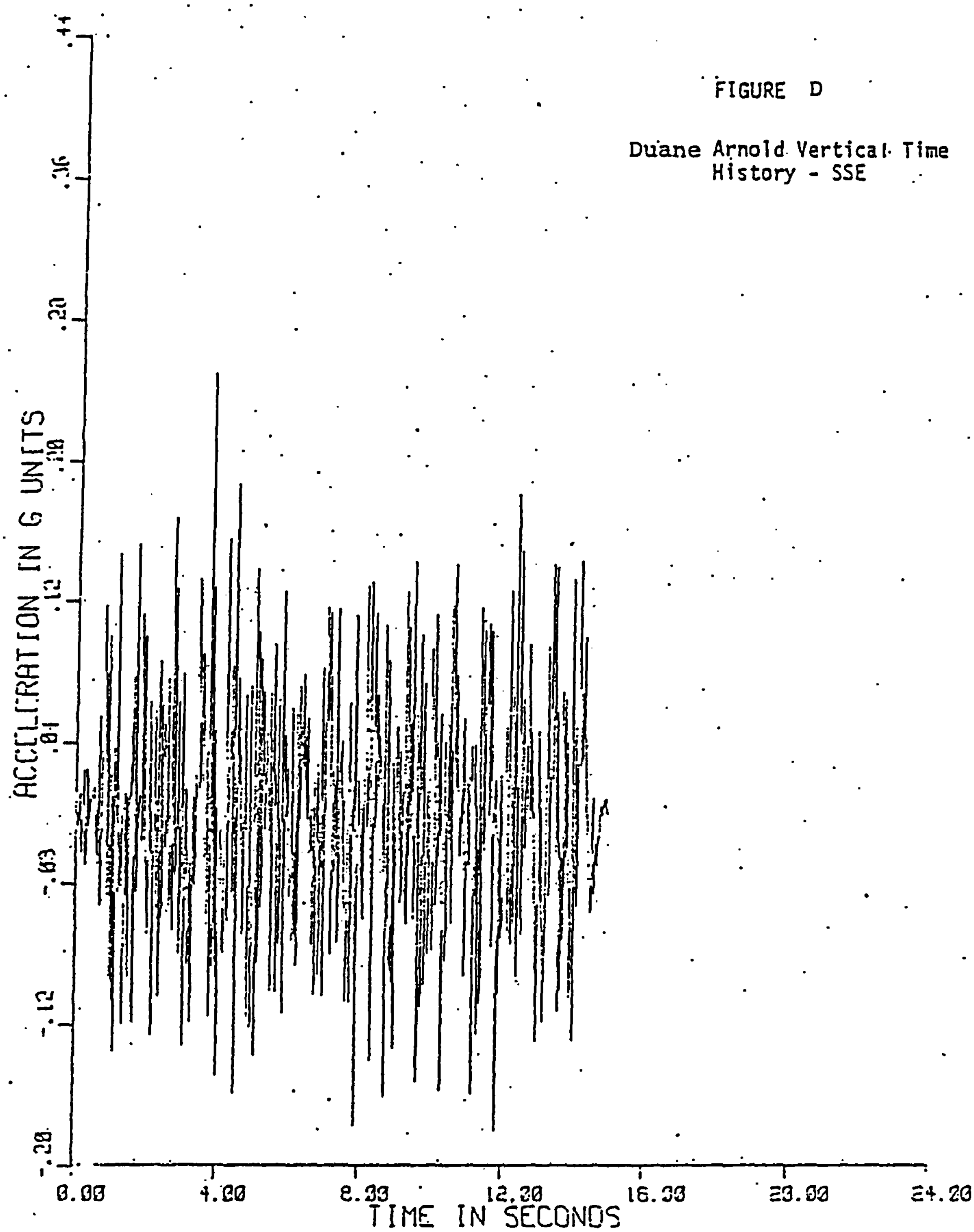


FIGURE C

Duane Arnold Horizontal Time History - SSE

FIGURE D

Duane Arnold Vertical Time History - SSE



3.0 MODEL FORMULATION

The details of the dynamic models shown in Figures 1 and 2 were supplied to JDS by PaRS in "Model Description, Formulation, and Assumptions for the Seismic Analysis of BWR Spent Fuel Racks," Revision No. 2, October 20, 1977, and included in Section 5.1. A brief description of the model will be given here, referred to Figure 1. The rack structure was idealized as a cantilever beam (nodes 11 - 15) connected to a horizontal beam (nodes 6 - 8) attached to vertical legs (nodes 5 - 6 and 9 - 8). The fuel bundle is represented by the beams connecting nodes 16 - 19, with node 16 coupled horizontally and vertically to node 11. Gap elements (for example, nodes 15 - 19 and 19 - 21) were used to simulate impact. The initial gap was set at 3/8", meaning if the fuel bundle translates horizontally more than 3/8" relative to the structure, impact will occur. Fifteen percent impact damping was utilized. The element connecting node 200 to 205 is a linear spring representing the stiffness of the pool floor. The mass of the floor tributary to the two racks is lumped at node 200.

Damping for the Duane Arnold racks was 6 percent of critical,

Damping was handled by inputting a value for beta, a constant which multiplies the stiffness matrix to form the damping matrix. Beta is given by the following expression:

$$\beta = 2 \quad \xi/\omega$$

A stiffness multiplier only was used since a significant amount of rigid body motion (rocking and sliding) was expected. The reason beta damping only is used when considerable rigid body motion is present is as follows: Assume the structure is sliding only; that is, no rocking and no vibration. At that point in time, we would desire zero damping since no vibration is taking place. It will be recalled that the mass, stiffness, and damping matrices for each of the structures were formed as super elements. Since no degrees of freedom are constrained in these super elements, the sum of all the terms in any row is zero, in the stiffness and therefore, the damping matrices, or

$$\sum_{i=1}^{n} K_{ij} = 0 \quad \text{and} \quad \sum_{i=1}^{n} C_{ij} = \sum_{i=1}^{n} \beta K_{ij} = 0$$

The damping force at any instant in time is the damping matrix times the <u>relative</u> velocity vector. For pure sliding, the relative velocity of each degree of freedom is the same; that is, $\dot{X}_i = \dot{X}$. The damping force is, therefore, given by:

$$F_D = \sum_{i=1}^{n} C_{ij} \dot{x}_i = \sum_{i=1}^{n} \beta K_{ij} \dot{x} = \beta \dot{x} \sum_{i=1}^{n} K_{ij} = 0$$

Thus, we introduce no artificial damping under pure rigid body motion. If alpha damping had also been included (α is a constant which multiplies the mass matrix), the same would not be true, since obviously the sum of each row in the mass matrix is not zero.

4.0 METHODS OF ANALYSIS

The digitized time histories discussed in Section 2.0 were used as input to a nonlinear transient dynamic analysis. The ANSYS (1) general purpose finite element program was utilized for the analysis. To reduce the amount of computing time required, the super element feature of the ANSYS program was utilized. The elements representing the floor formed one super element. The beam elements and masses representing the rack structure each formed super elements, and the fuel bundles formed super elements. Thus for a two-rack analysis, five super elements were required; and for a single-rack analysis, three super elements were required. The main structure; that is, the gap and interface elements, have their mass, stiffness, and damping matrices reformulated at each time step. The super element feature also allows the use of dynamic degrees of freedom in the super elements; thus rotations and most axial degrees of freedom can be excluded.

5.0 RESULTS

As mentioned in Section 1.0, the single-rack analyses were done to determine maximum displacement only. Figures 3 and 4 give the horizontal displacement of node 15 relative to the horizontal input. The peak value for Duane Arnold is 1.05 inches.

The greatest amount of data resulted from the two-rack analyses. The following sets of plots all refer to Duane Arnold. In Figures 5 through 14 are given the plots of the gap forces versus time. They are labeled with reference to Figure 2. In Figures 15 through 18 are given the plots of the vertical force in the interface elements. Figure 19 gives a plot of the sum of these vertical forces versus time. The sum of the horizontal forces in the four interface elements is given in Figure 20. Figure 21 is the only displacement plot obtained from this two-rack analysis. It is a plot of the vertical displacement of node 200 relative to the input displacement at node 205. To obtain the force in the floor spring at any instant in time, simply multiply displacement by the spring constant (see Appendix C).

The next set of plots (Figures 22 through 43) are the nodal forces versus time. They are labeled according to Figure 2. From this group are drawn the maximum values and load cases then compiled. Load cases corresponding to times when each nodal force is maximum, plus one case when the sum of the horizontal forces in the interface elements was maximum are presented in Tables 1 and 2 for Duane Arnold. An underscored force indicates this is the component which was maximum at that particular time.

REFERENCES

(1) ANSYS User's Manual, Swanson Analysis Systems, Elizabeth, Pennsylvania.

(2) Dynamic Time History Analysis of the Pilgrim Nuclear Power Station 7x.0 and 10x10 Spent Fuel Rack Considering Potential for Rack Lift Off and Sliding, by J.D. Stevenson, Consultants, for PaR Systems Corp.. May 15,1977.

(3) SIMQKE Computer Program

(4) D. Gasparini and E.H. Vanmarcke, "Simulated Earthquake Motions Compatible with Prescribed Response Spectra," MIT Publication No. R76-4, 1976.

CALCULATION PAD
McKee
Form H-892 9/76

TO:
SUBJECT: 2-Rack Analysis
MADE BY: J. J. Kidder DATE 5-16-77
CHECKED BY: L. A. Beegman DATE 12-6-77
APPROVED BY: DATE 12-6-77

NEGOTIATION NO
CONTRACT NO 1637X27
FLOW SHEET NO
AREA NO
ITEM NO
DRAWING NO Figure 1
PAGE OF

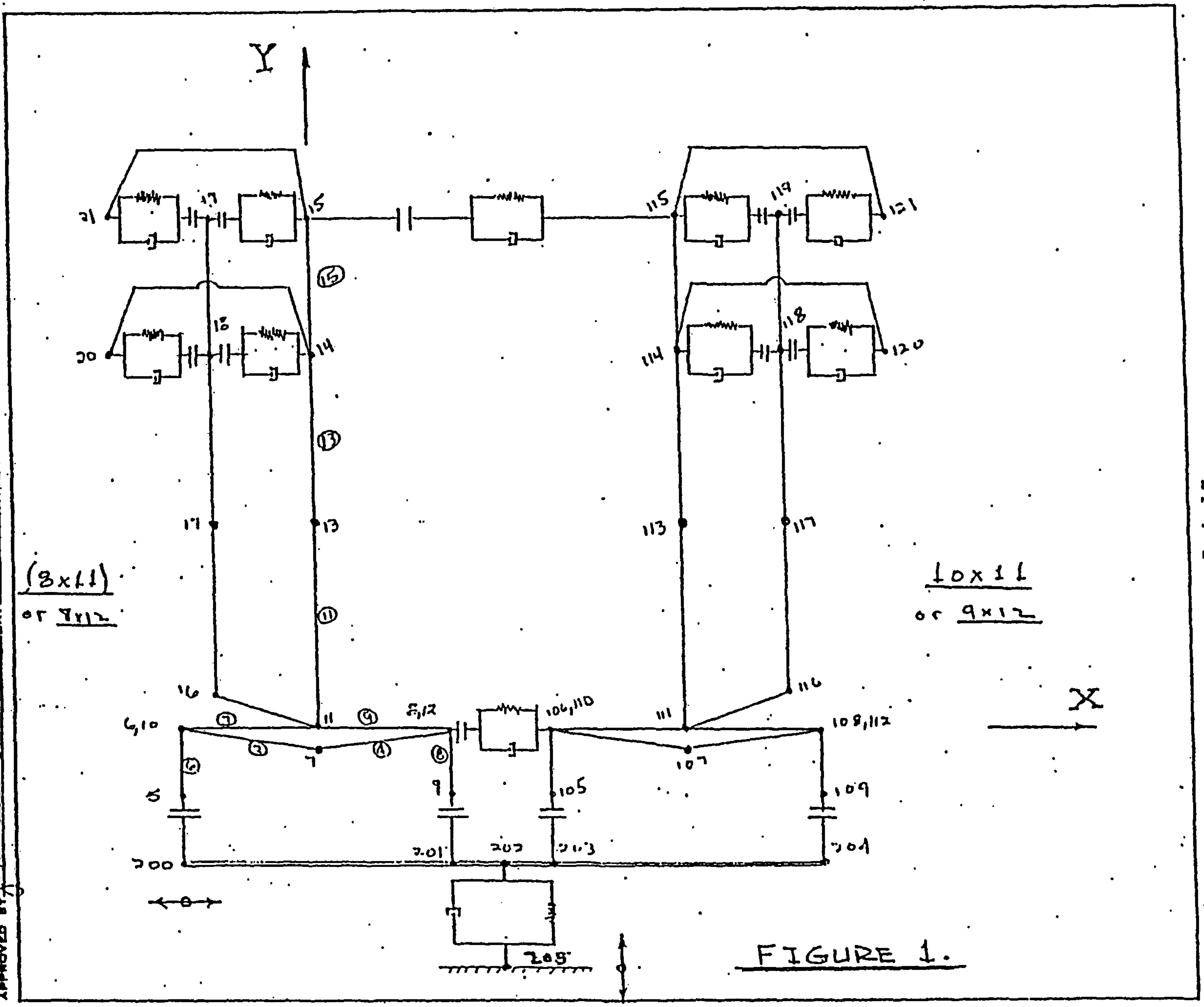


FIGURE 1.

CALCULATION PAD
McKee
Form K-892 9/76

TO:
SUBJECT: Truck Model
MADE BY D. Kirkner DATE
CHECKED BY L. A. Bergman DATE 12-6-77
APPROVED BY J. C. Thomson DATE 12/6/77

NEGOTIATION NO.
CONTRACT NO.
FLOW SHEET NO.
AREA NO.
ITEM NO.
DRAWING NO. FIGURE 2
PAGE OF

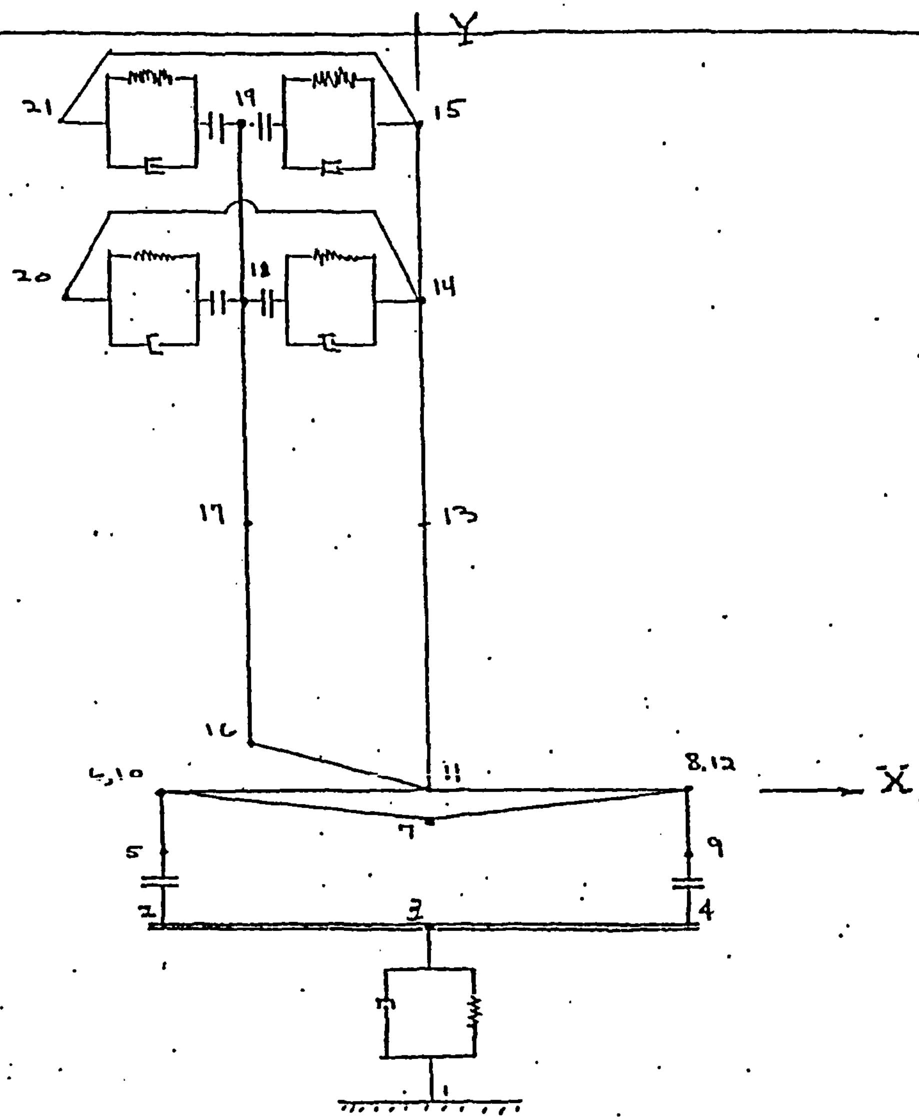


FIGURE 2

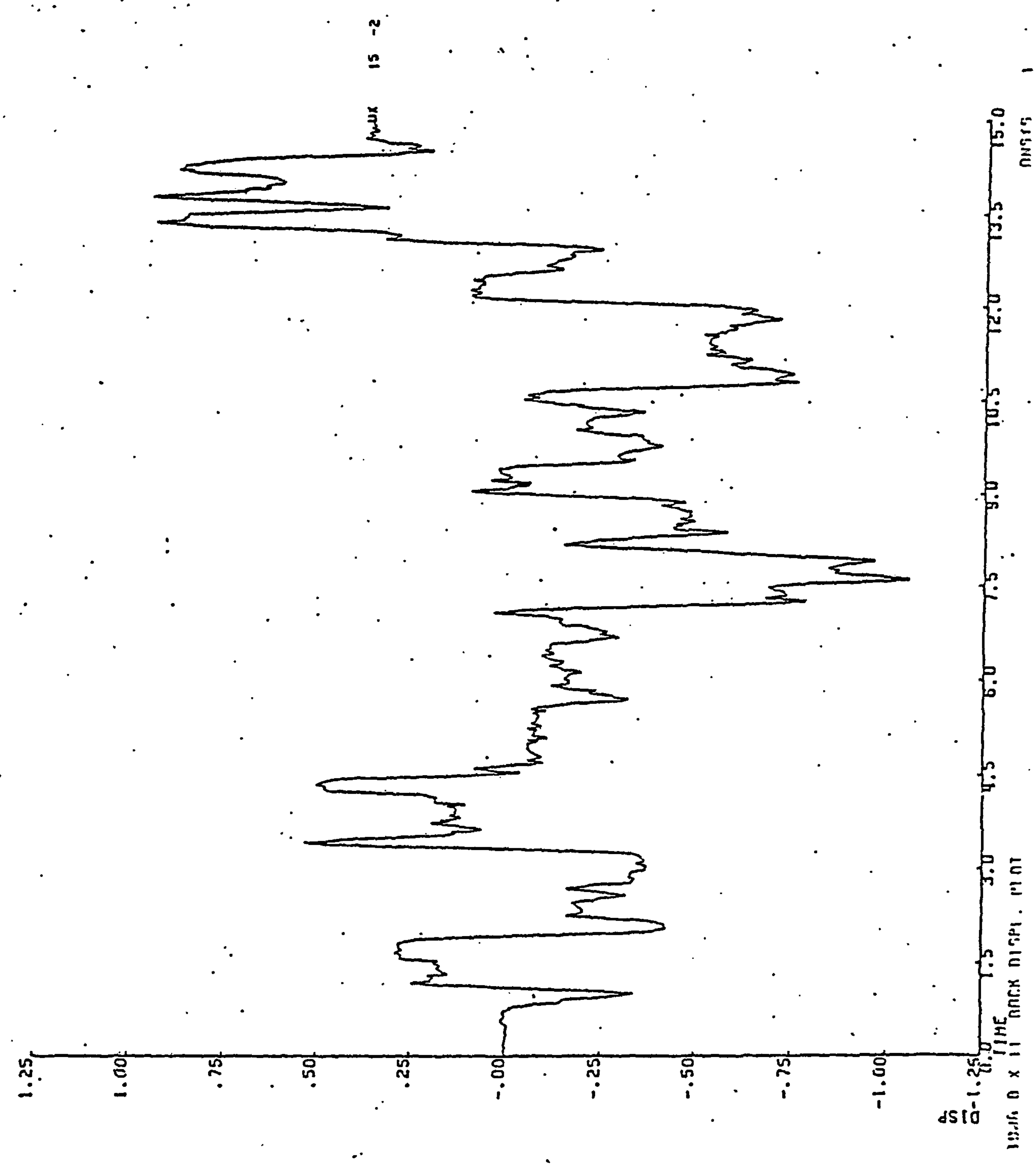


FIGURE 3 - Relative Horizontal Displacement - Node 15

NOT USED

FIGURE 4

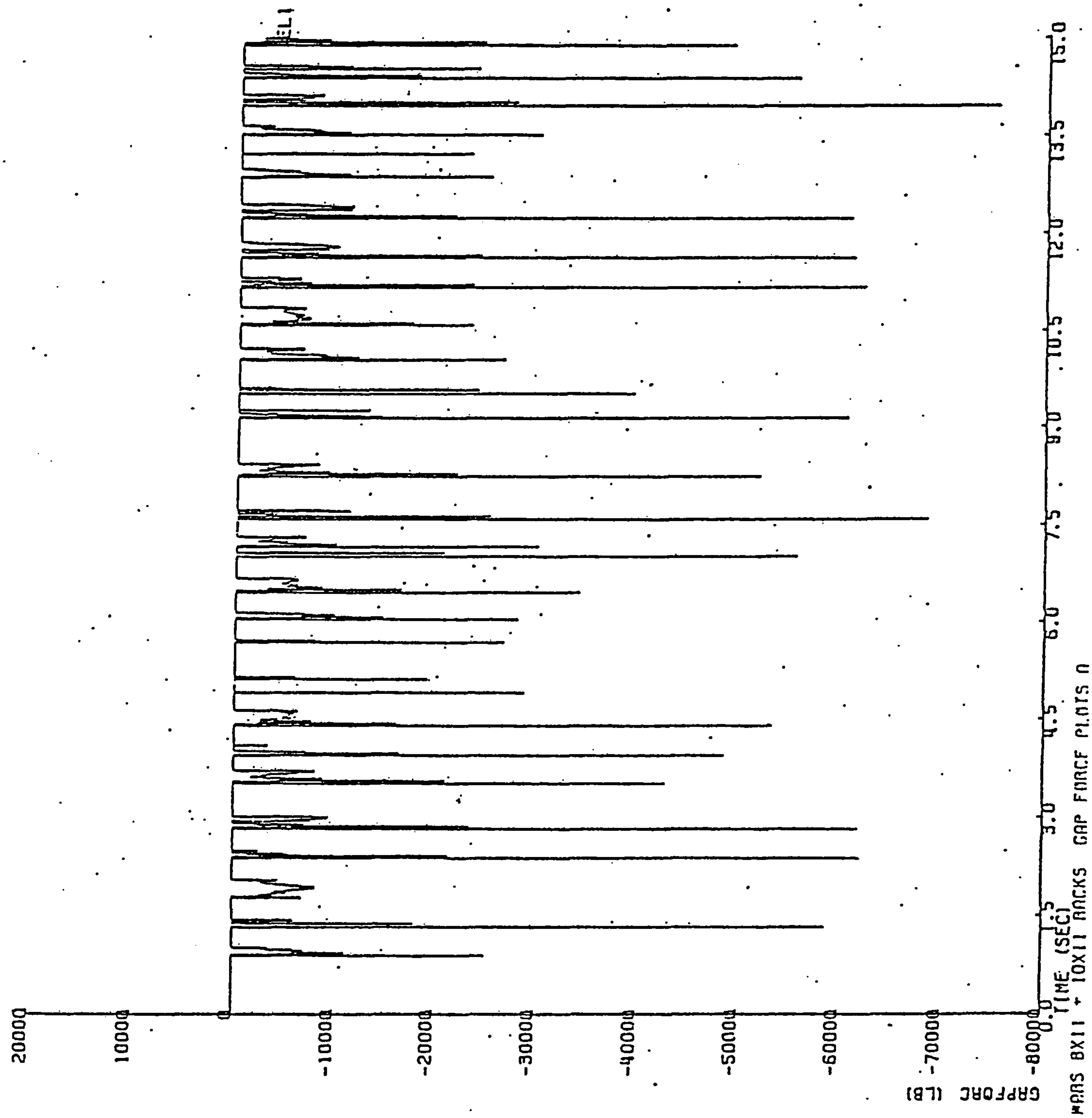


FIGURE 5 - Gap Force - Nodes 15-19

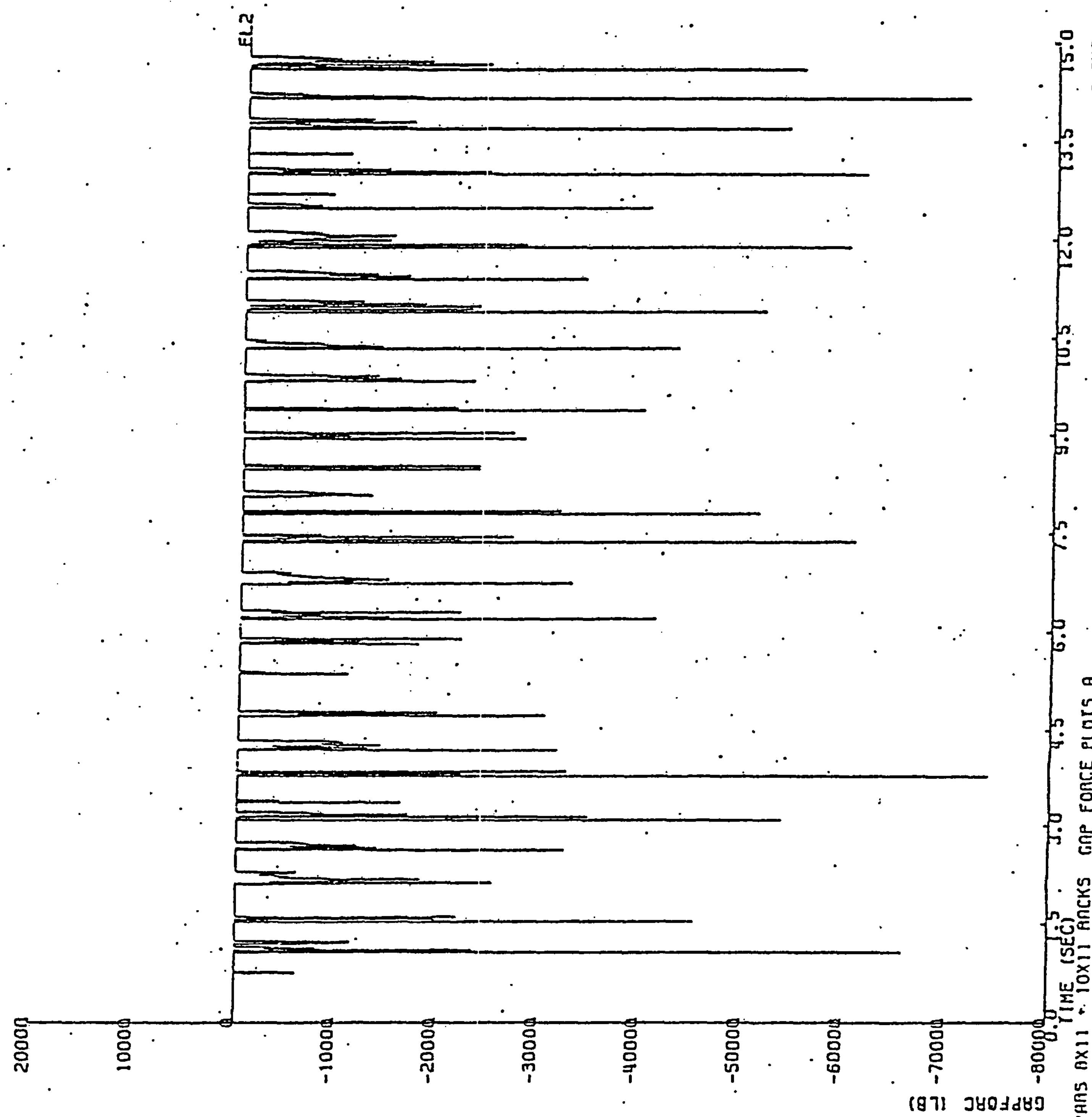


FIGURE 6 - Gap Force - Nodes 19-21

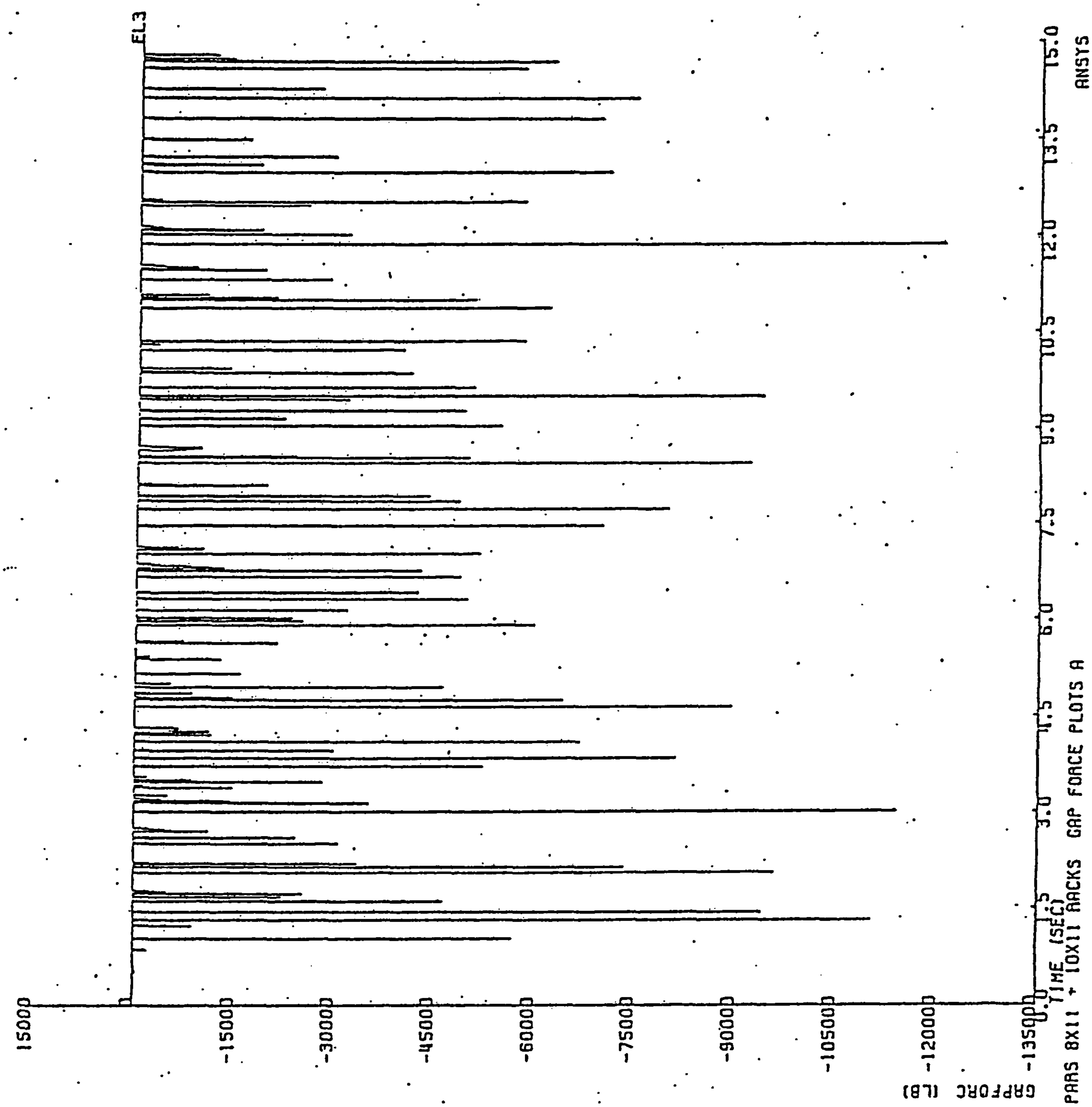


FIGURE 7 - Gap Force - Nodes 15-115

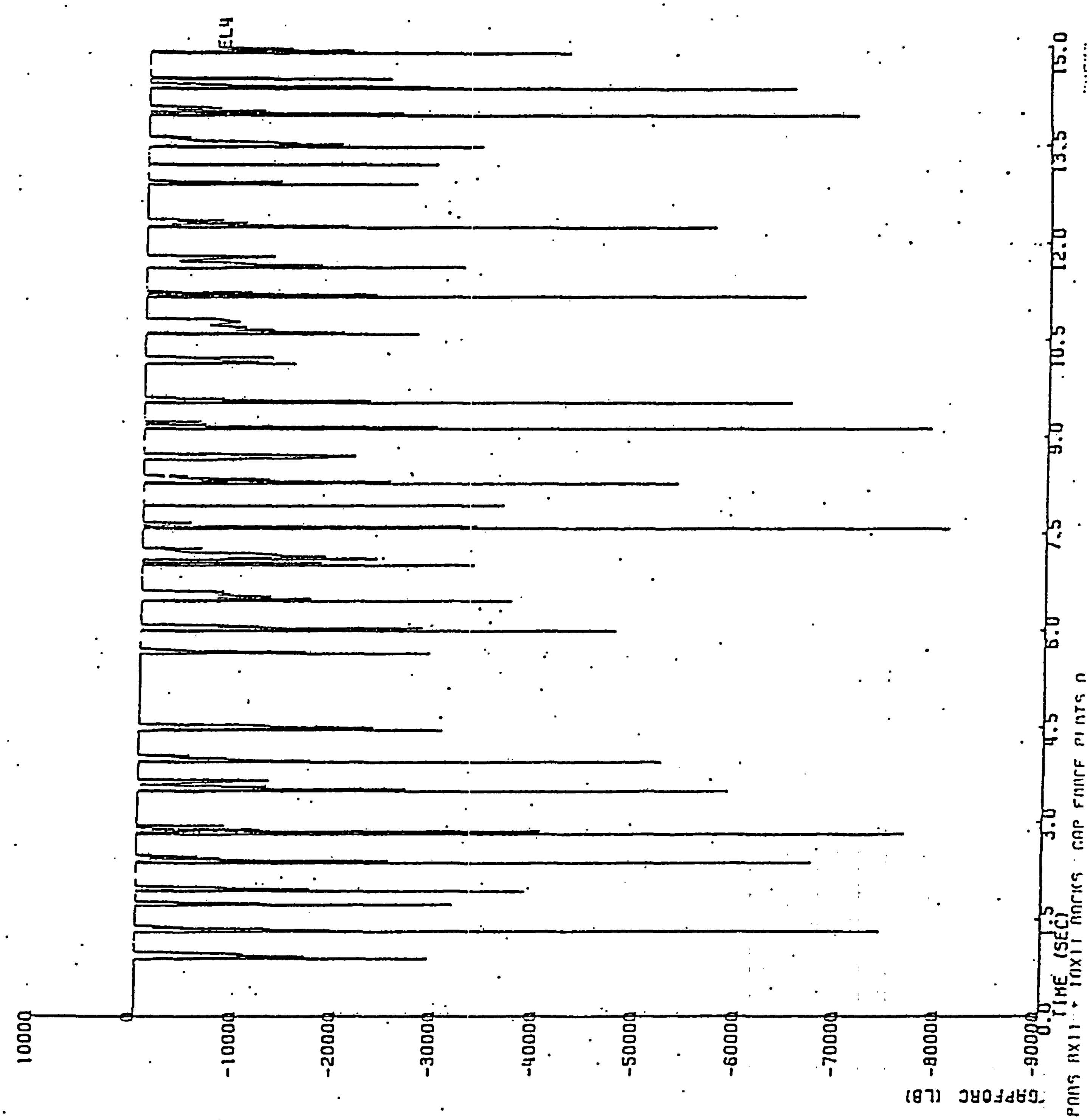


FIGURE 8 - Gap Force - Nodes 115-119

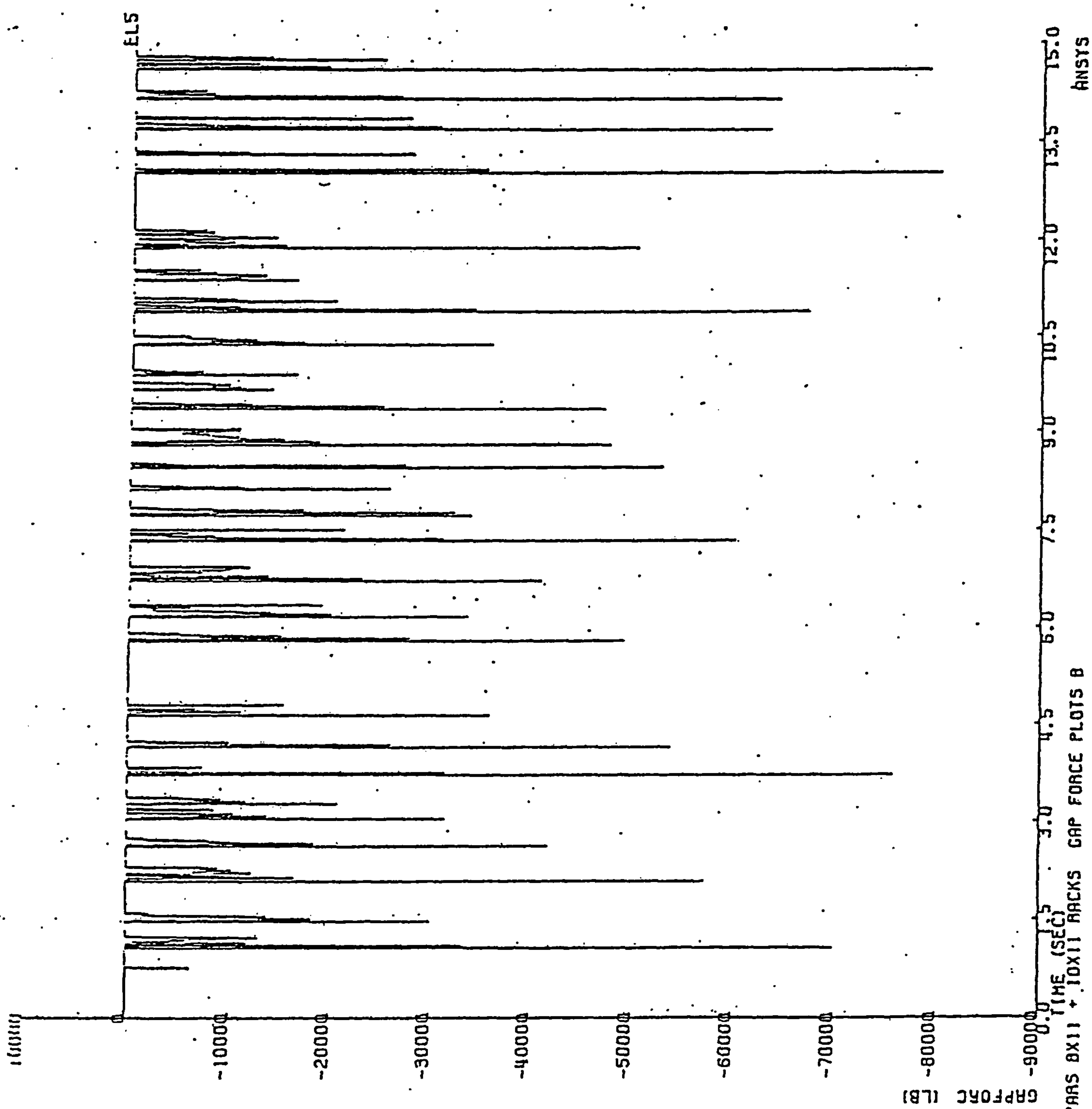


FIGURE 9 - Gap Force - Nodes 119-121

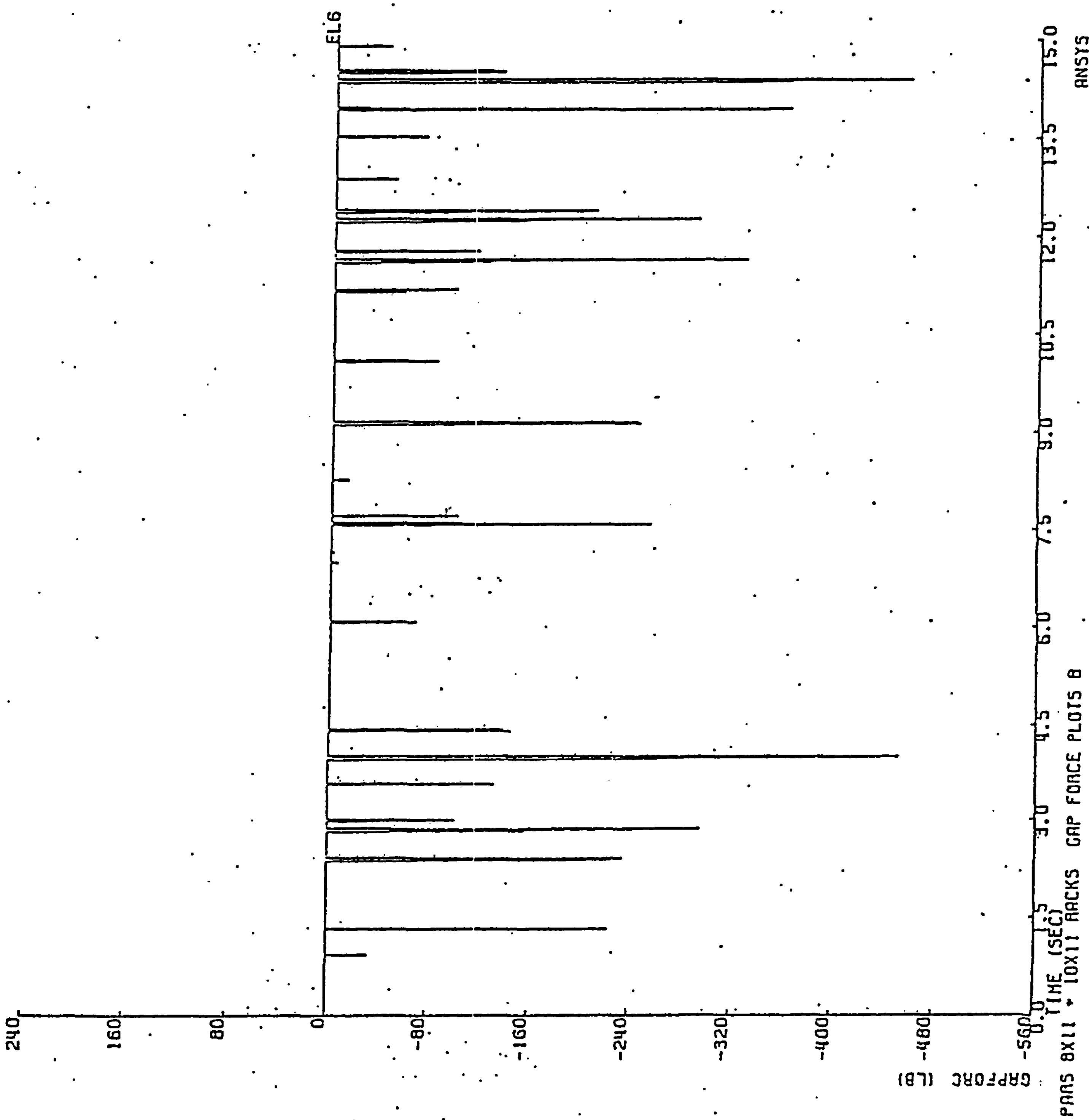


FIGURE 10 - Gap Force - Nodes 14-18

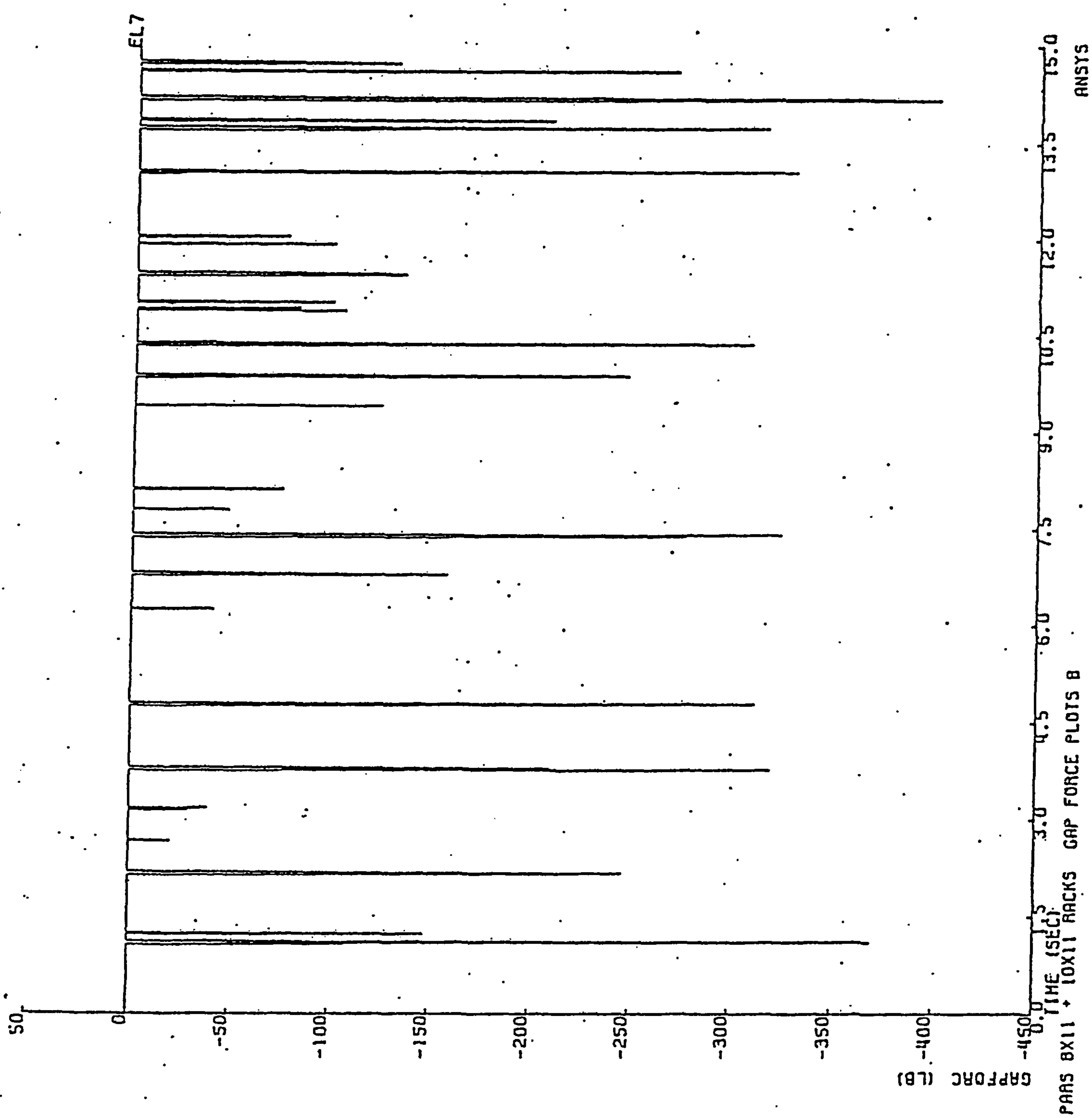


FIGURE 11 - Gap Force - Nodes 18-20

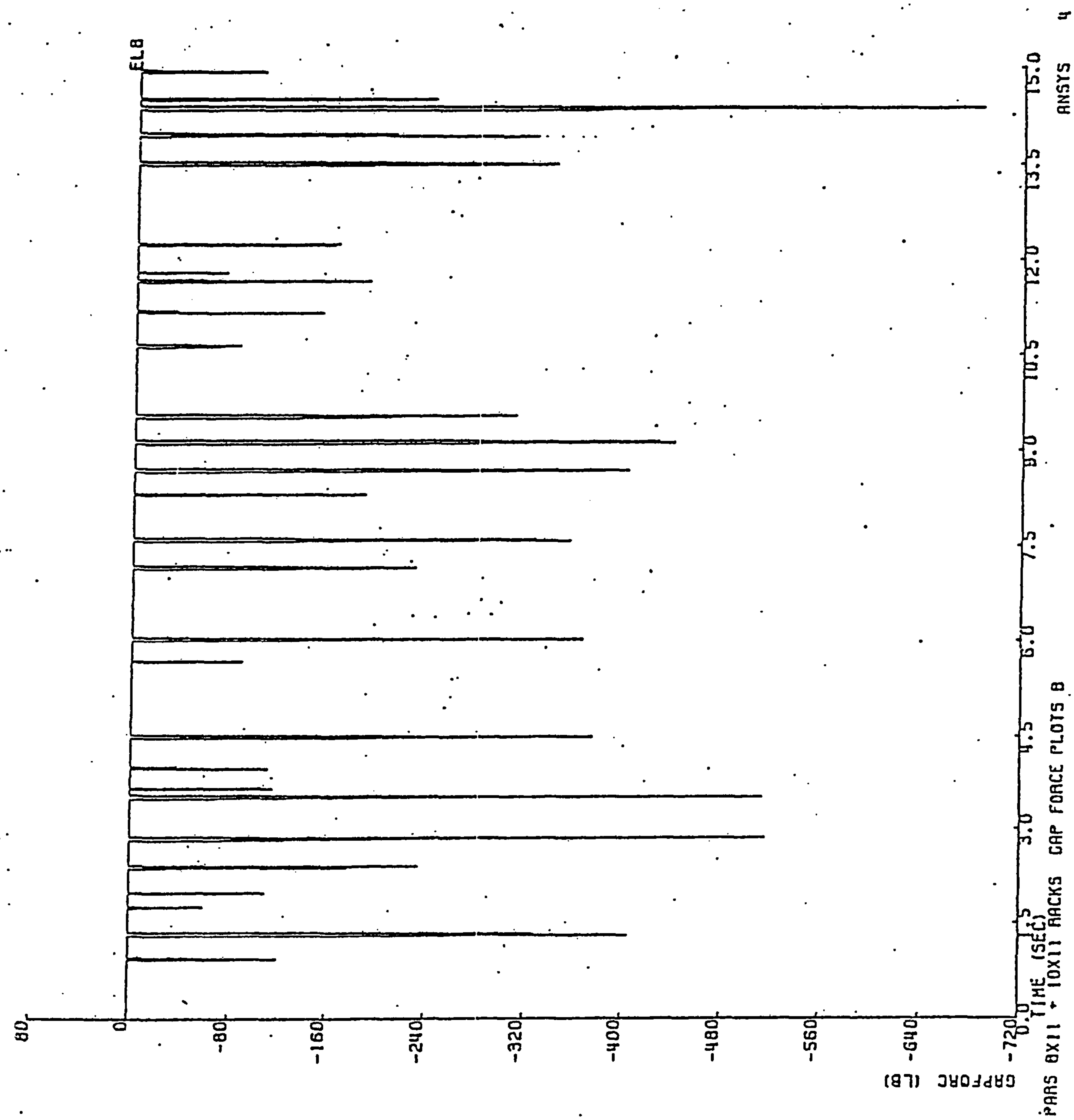


FIGURE 12 - Gap Force - Nodes 114-118

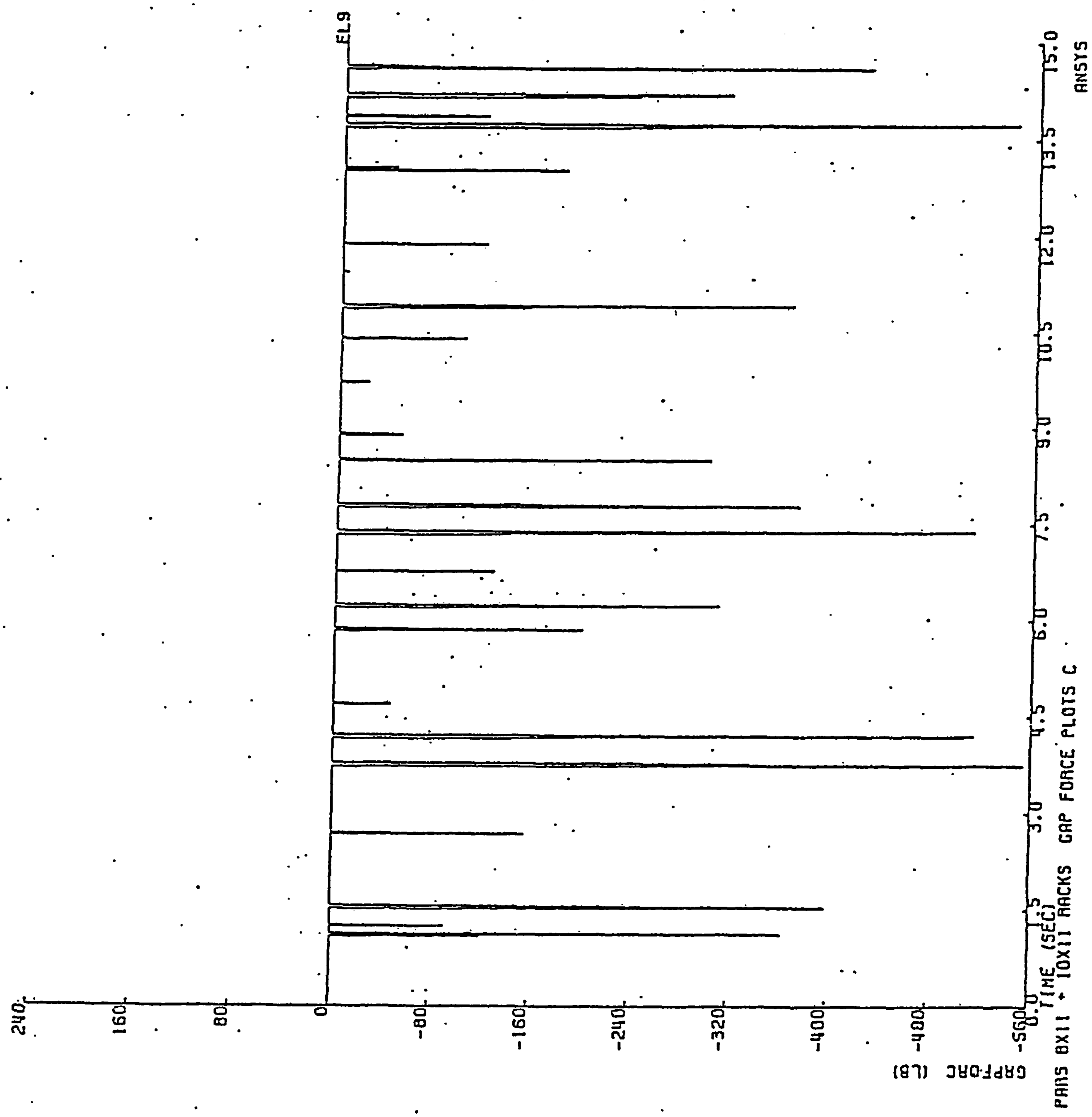


FIGURE 13 - Gap Force - Nodes 118-120

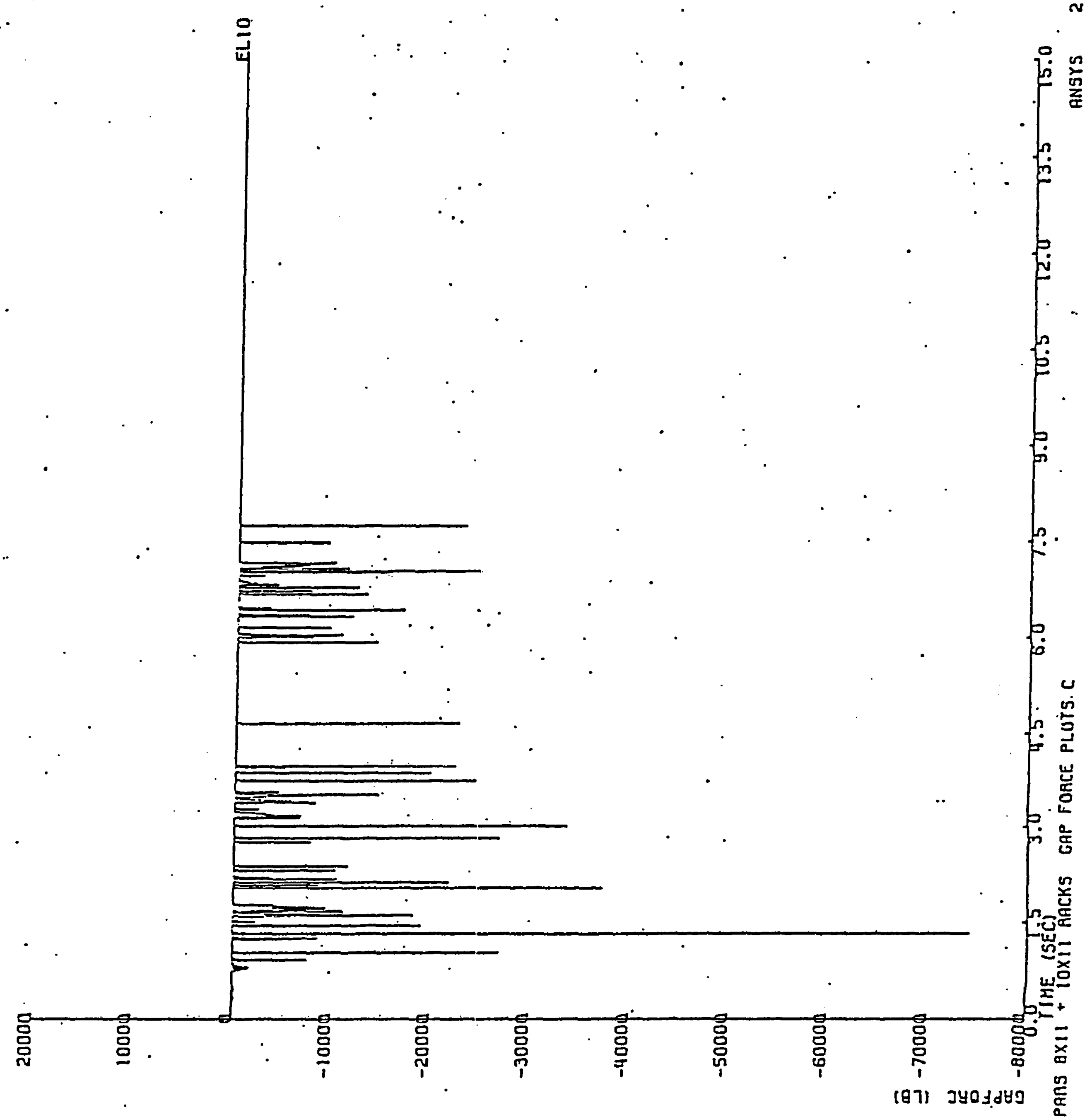


FIGURE 14 - Gap Force - Nodes 12-110

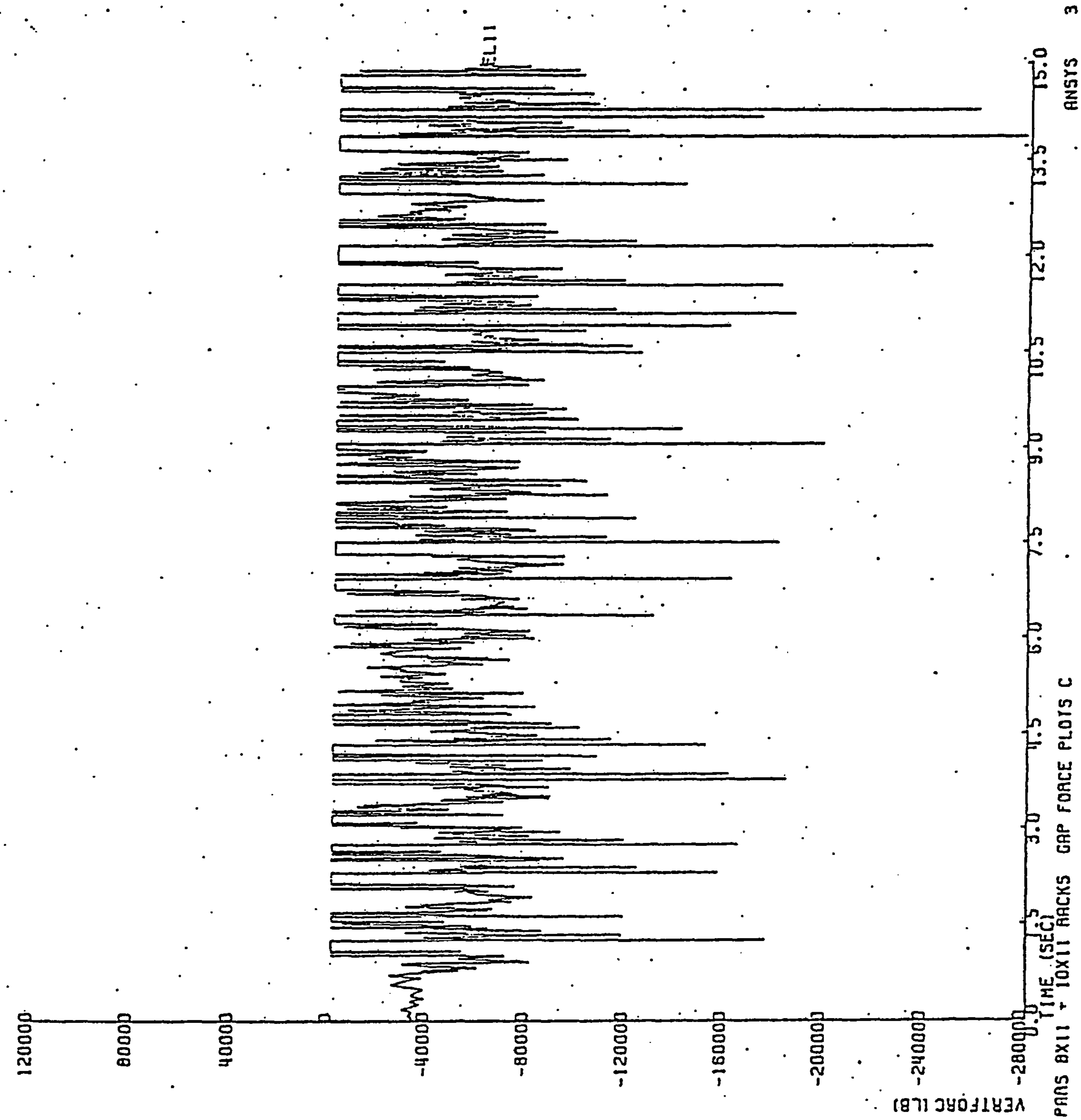


FIGURE 15 - Vertical Force Interface Element - Nodes 200-5

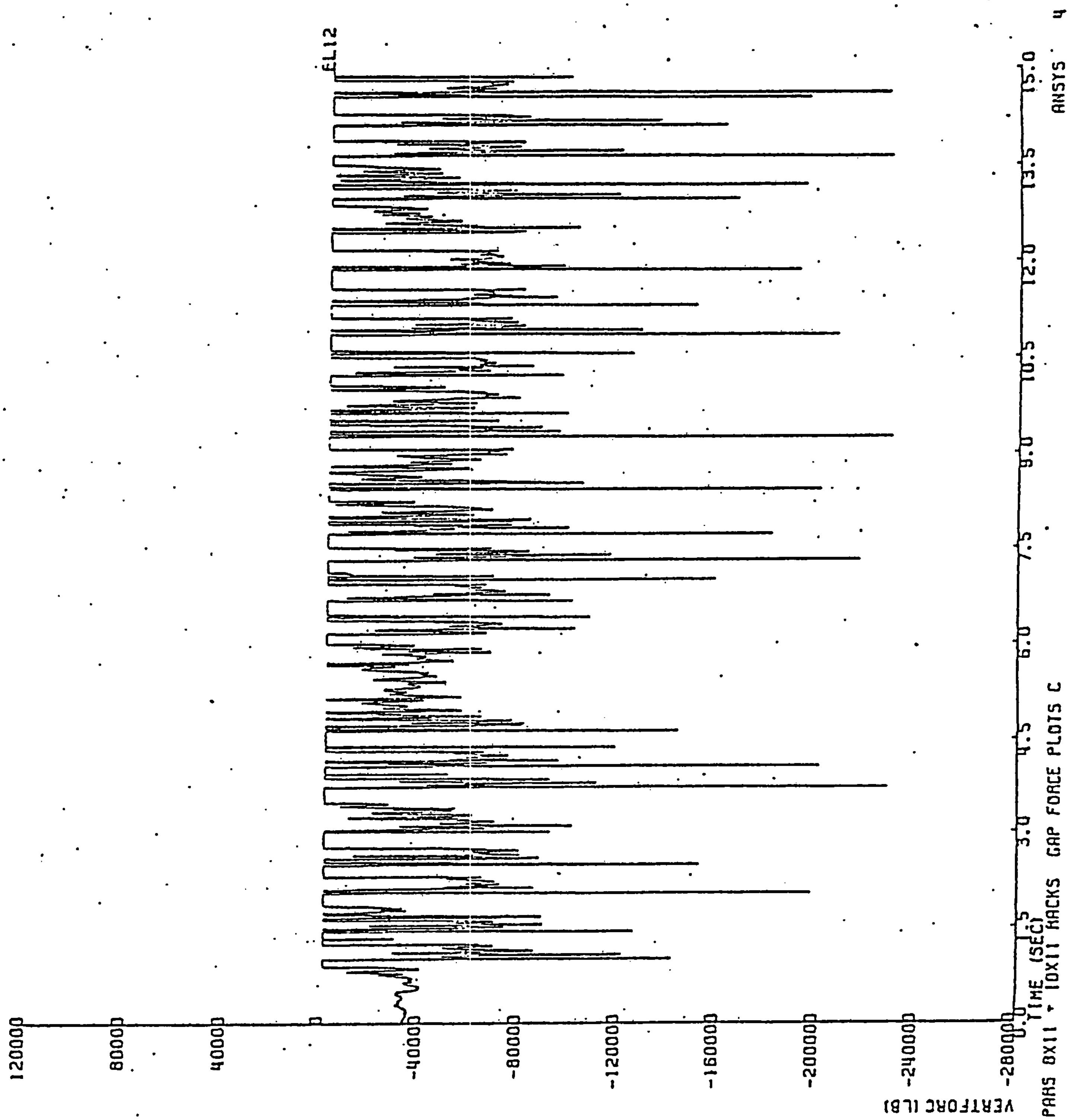


FIGURE 16 - Vertical Force Interface Element - Nodes 201-9

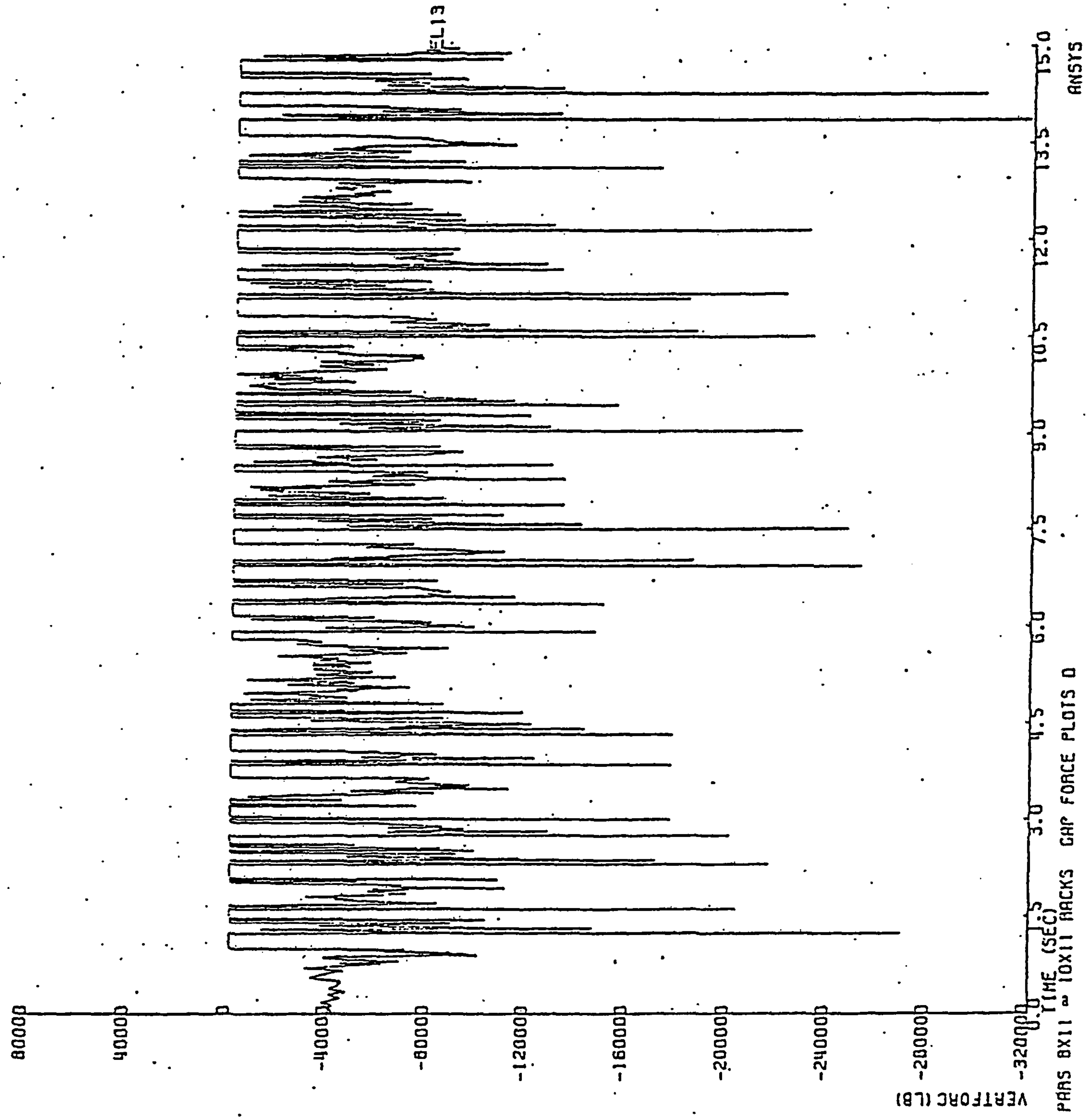


FIGURE 17 - Vertical Force Interface Element - Nodes 203-105

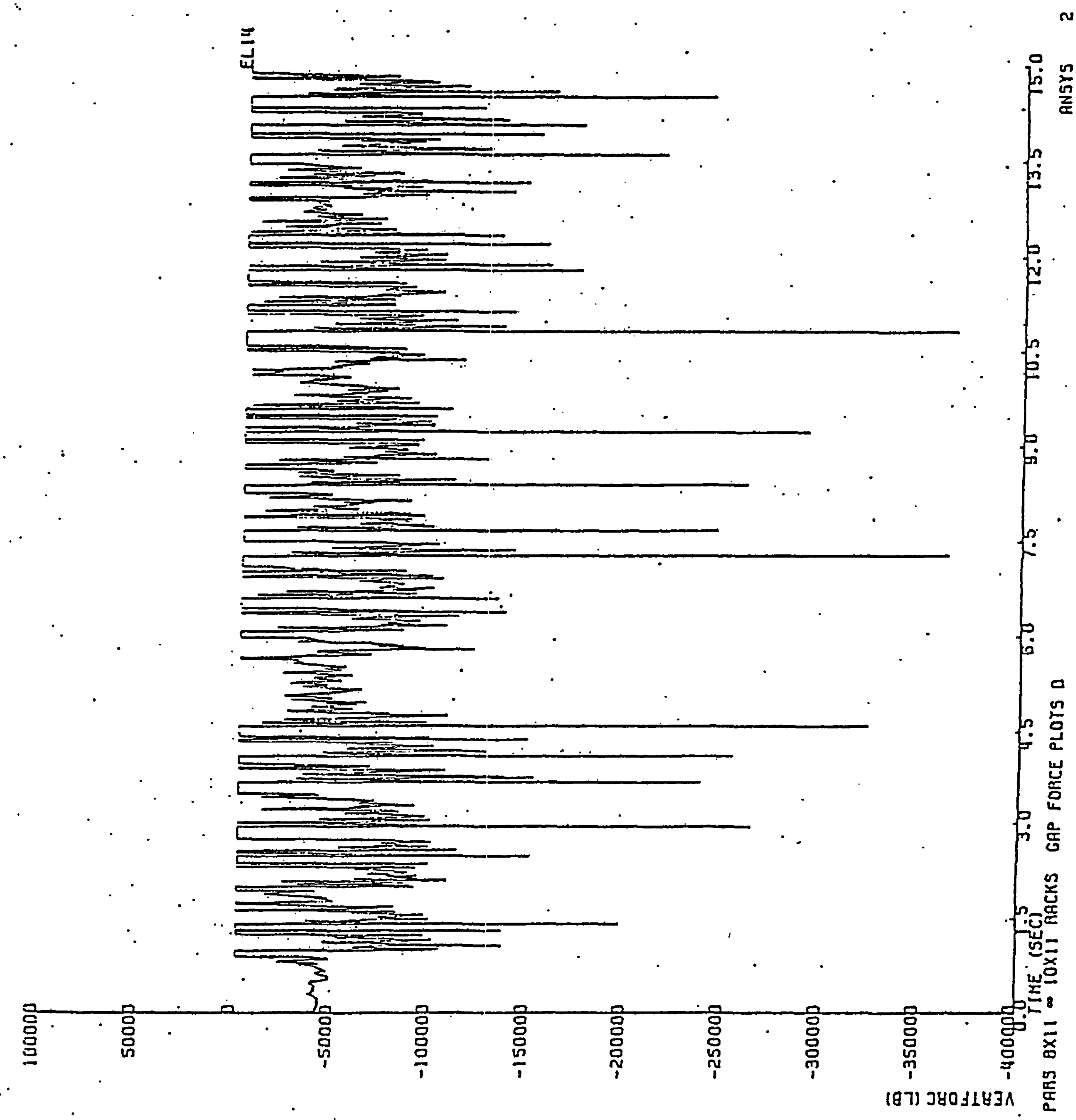


FIGURE 18 - Vertical Force Interface Element - Nodes 204-109

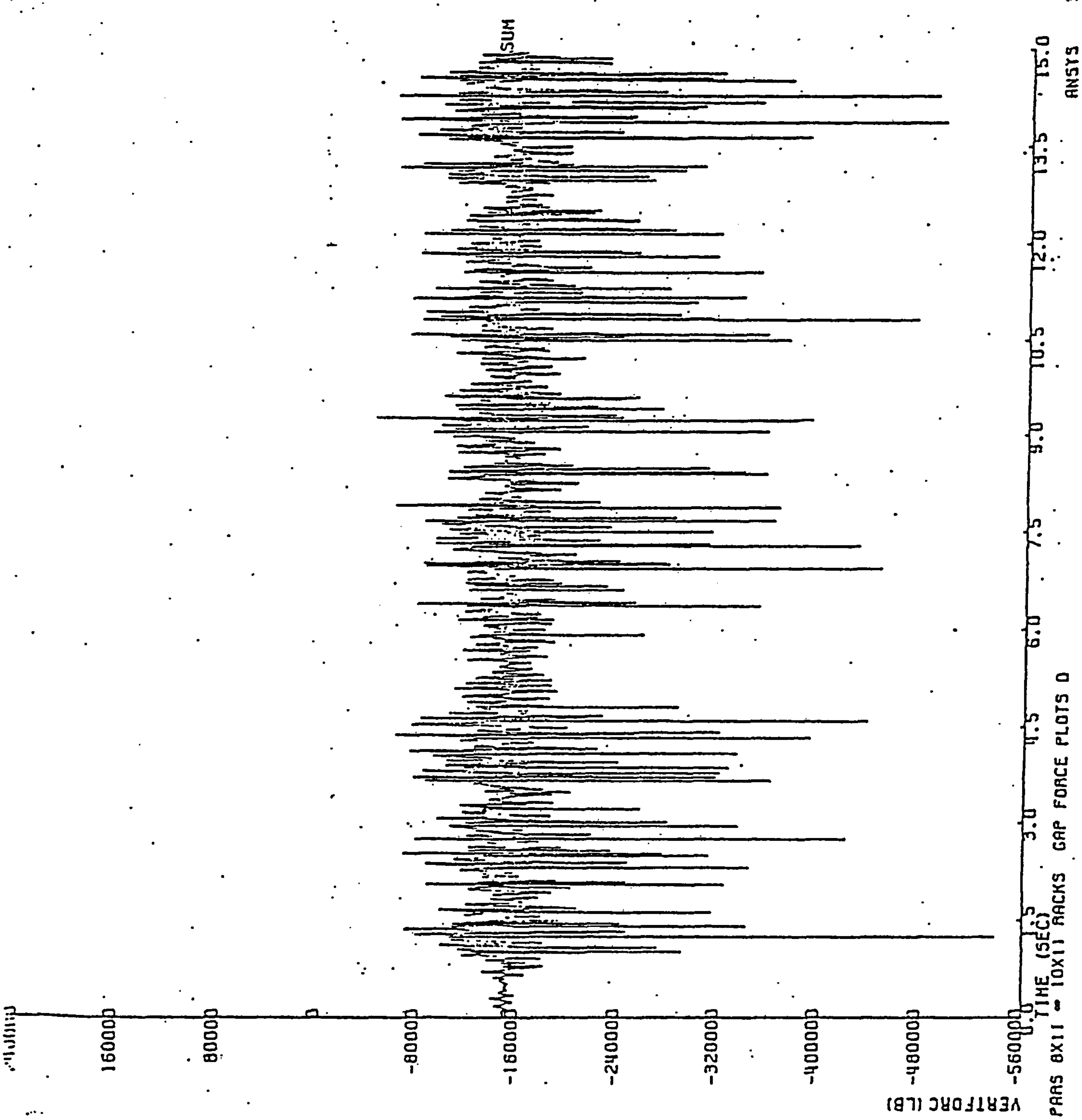


FIGURE 19 - Sum of Vertical Force in Interface Elements

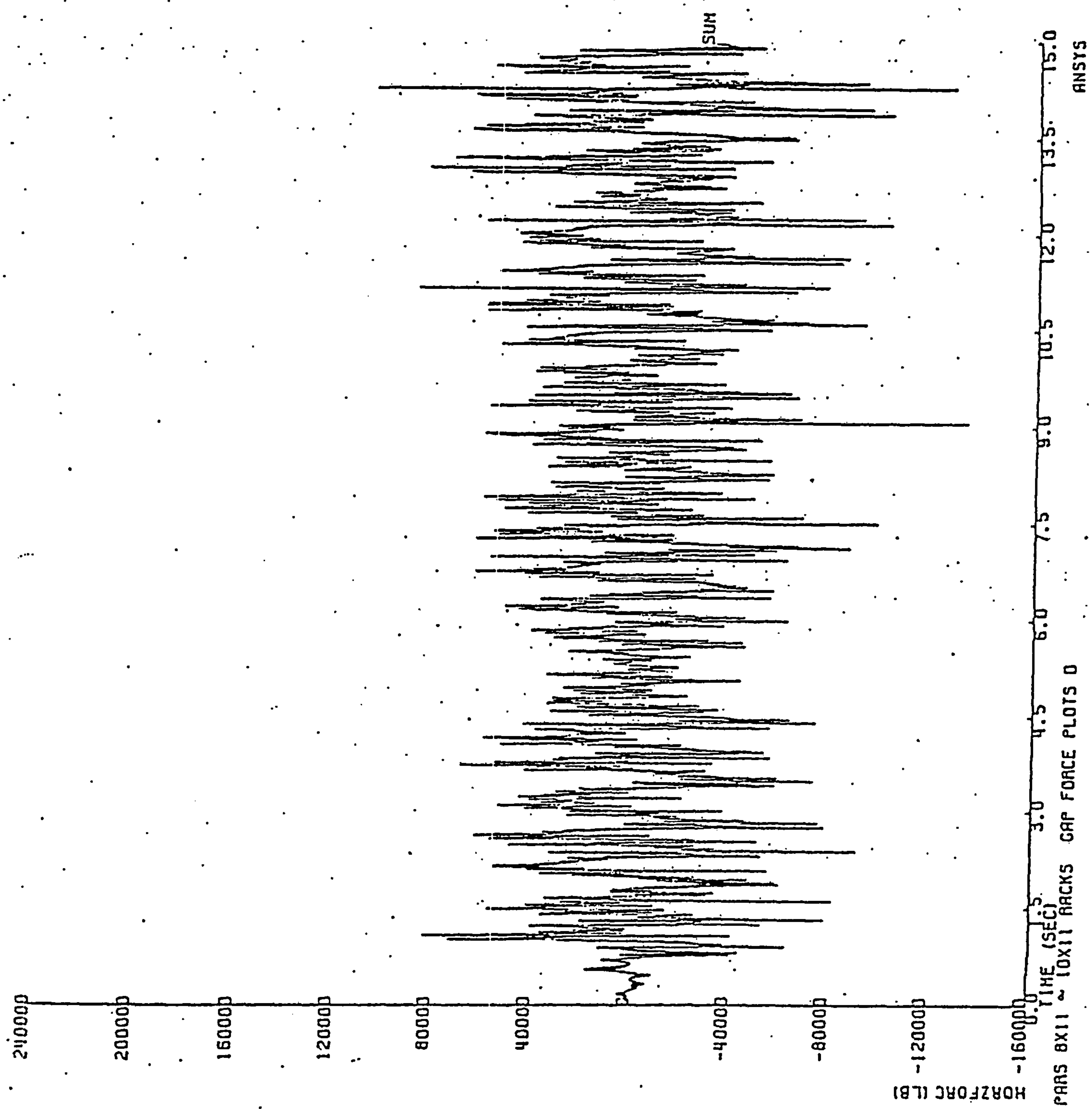


FIGURE 20 - Sum of Horizontal Forces in Interface Elements

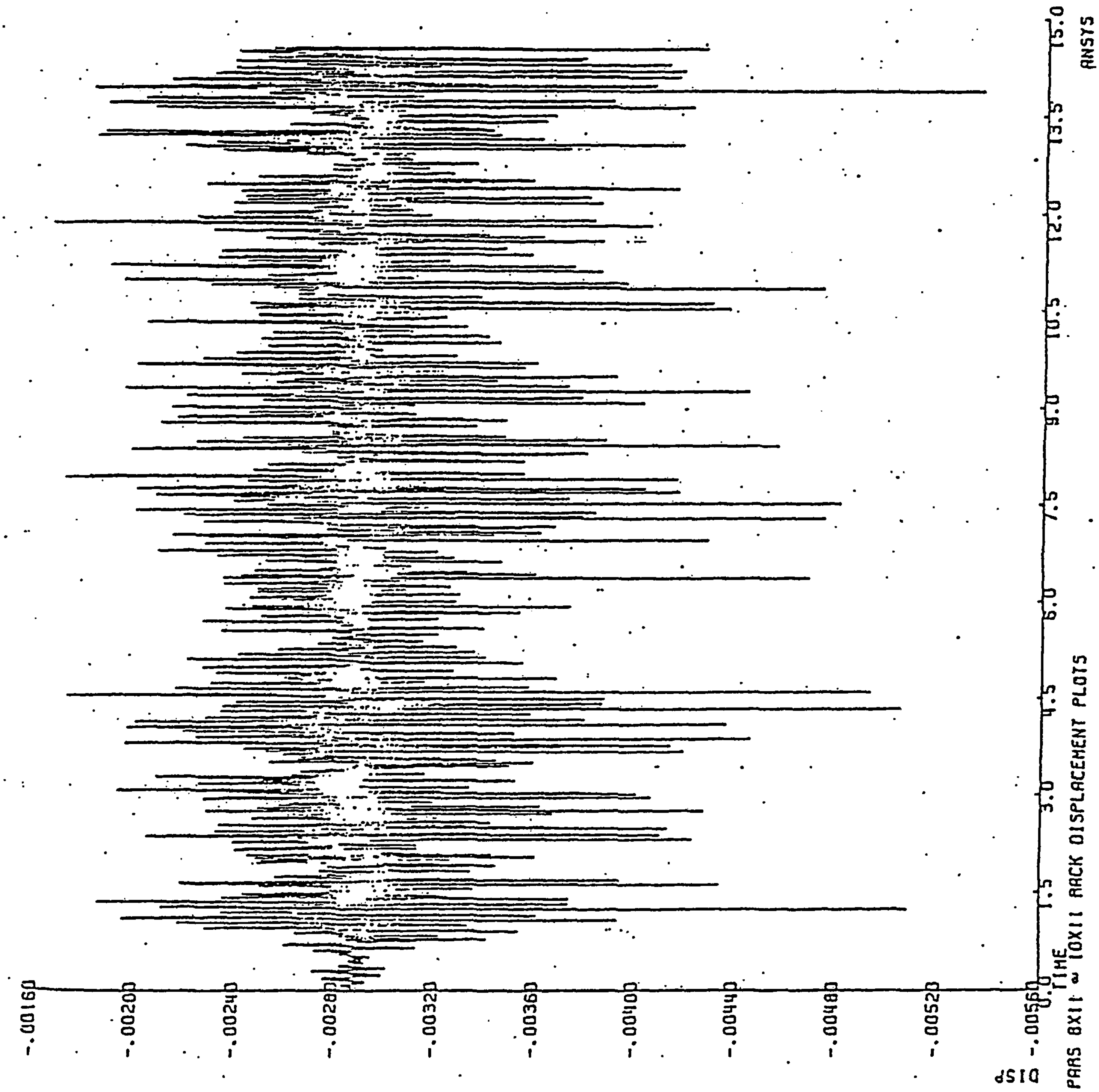


FIGURE 21 - Relative Vertical Displacement - Node 200-205

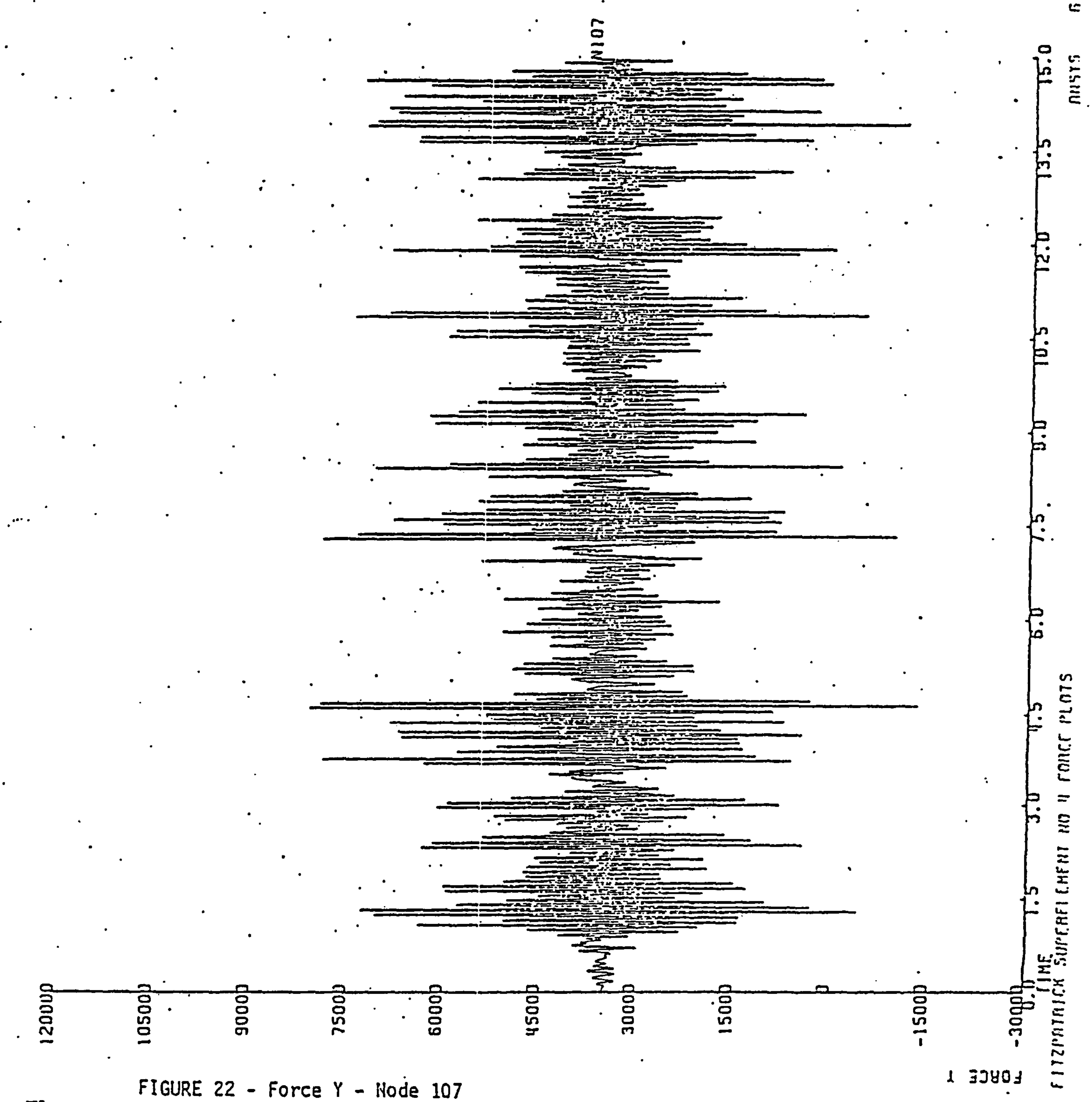


FIGURE 22 - Force Y - Node 107

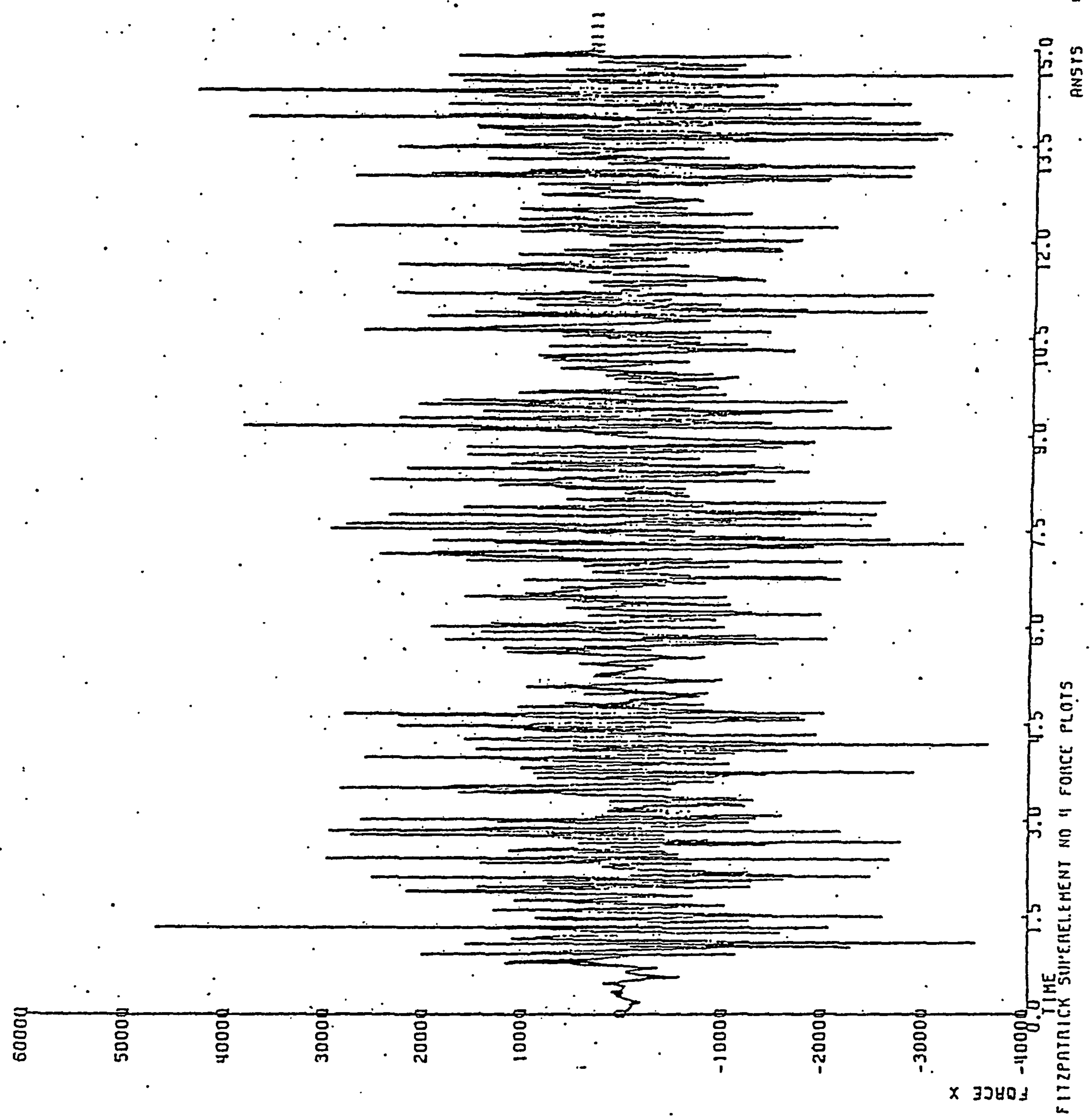


FIGURE 23 - Force X - Node 111

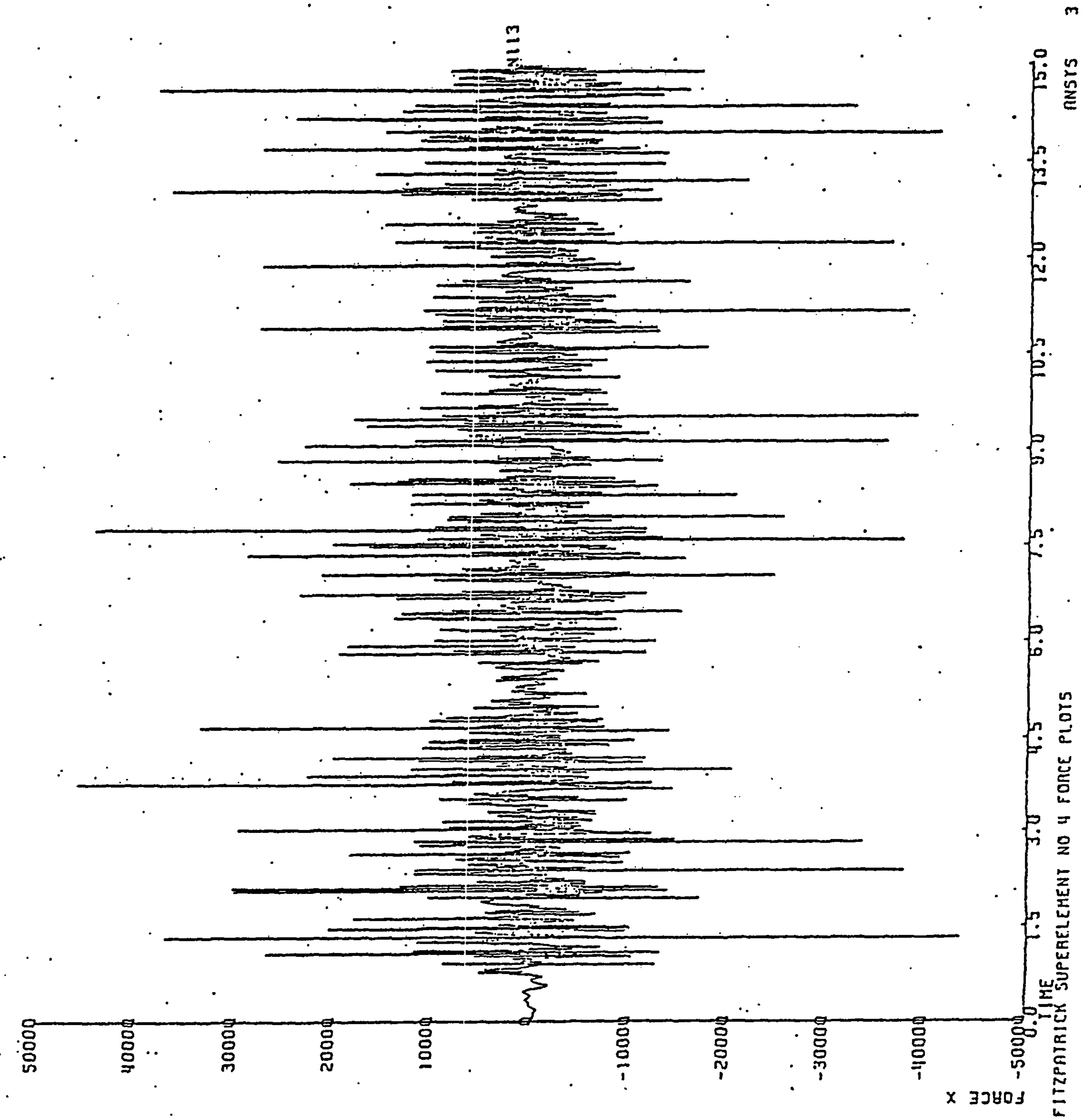


FIGURE 24 - Force X - Node 113

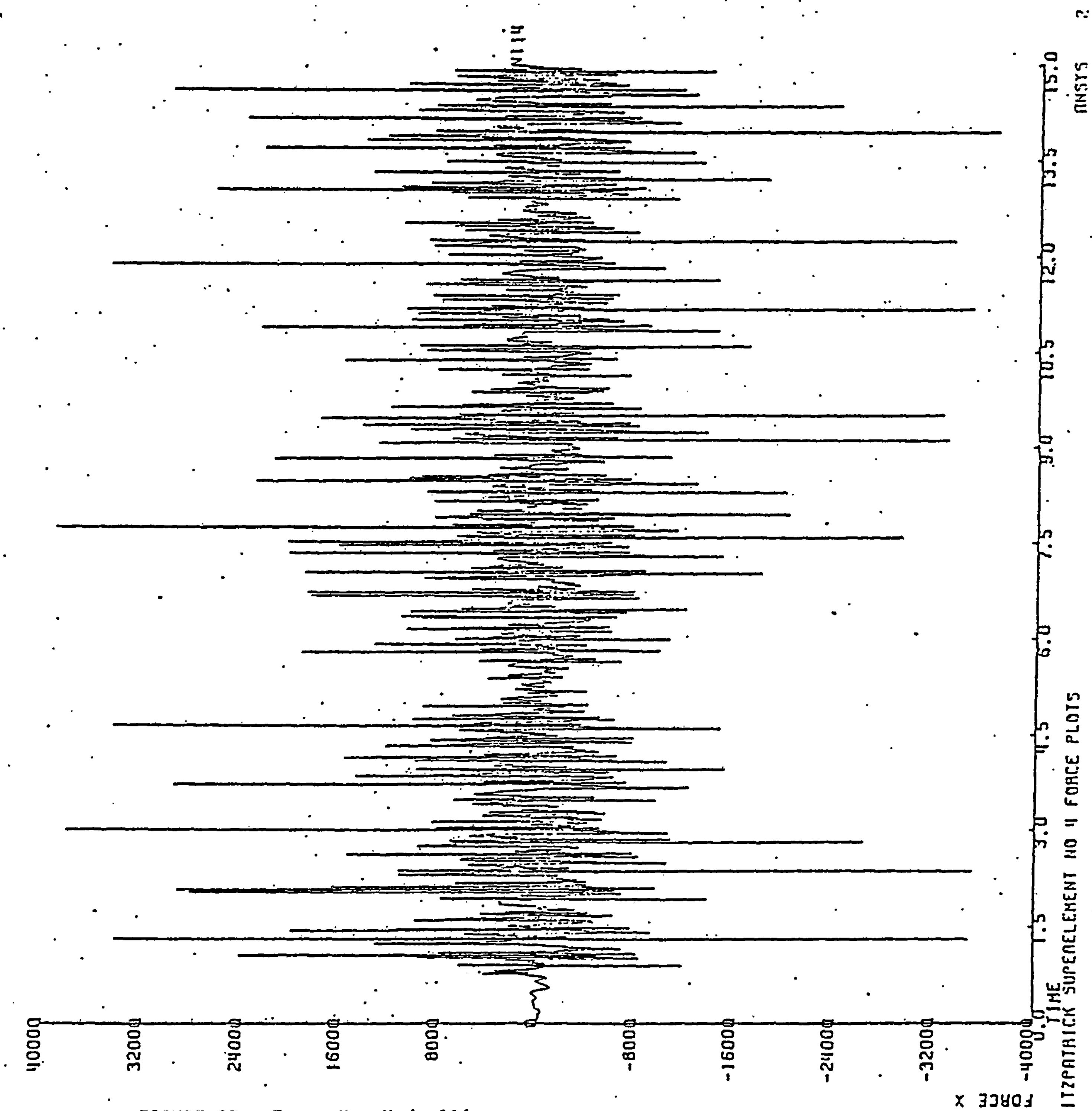


FIGURE 25 - Force X - Node 114

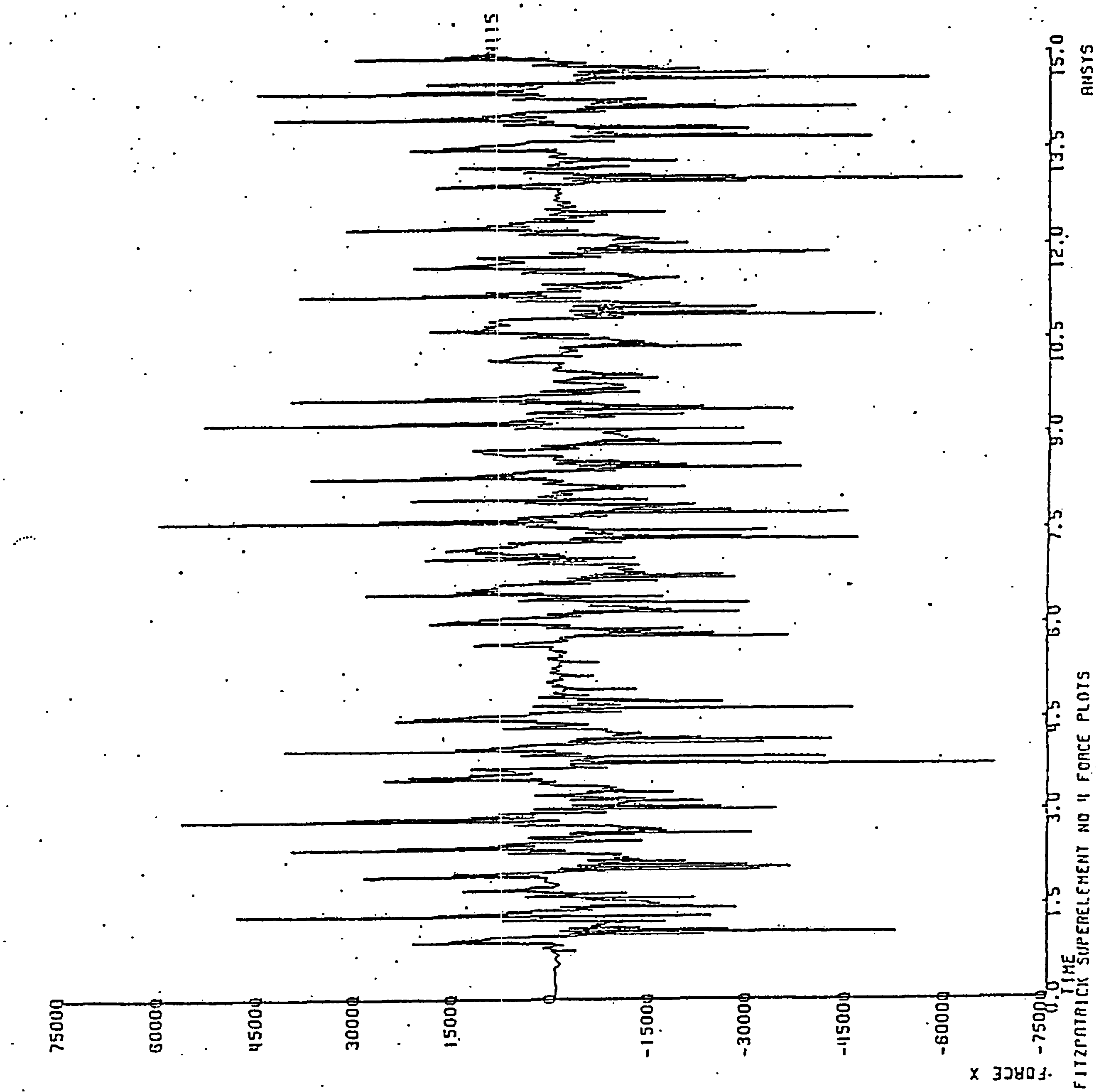


FIGURE 26 - Force X - Node 115

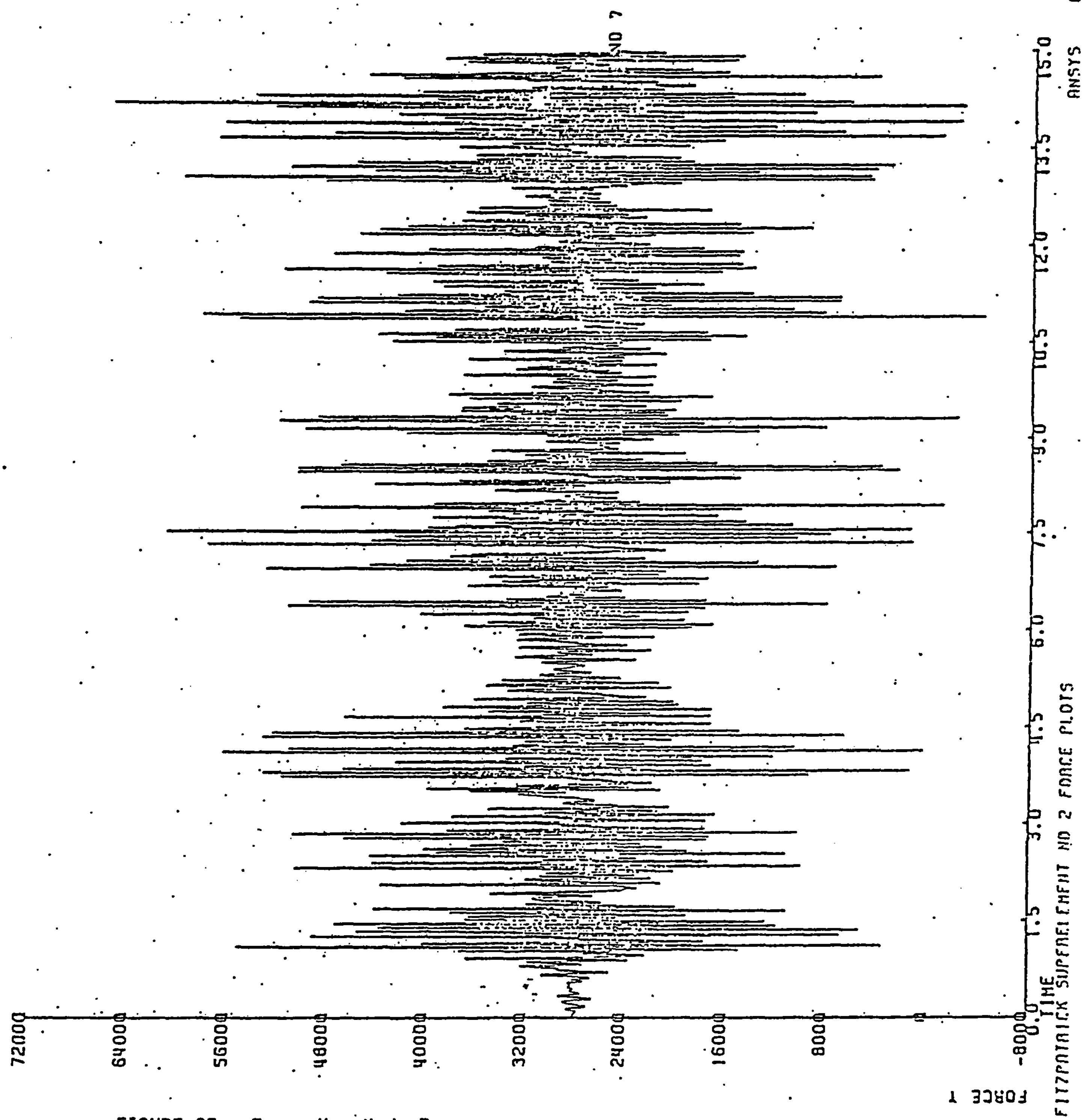


FIGURE 27 - Force Y - Node 7

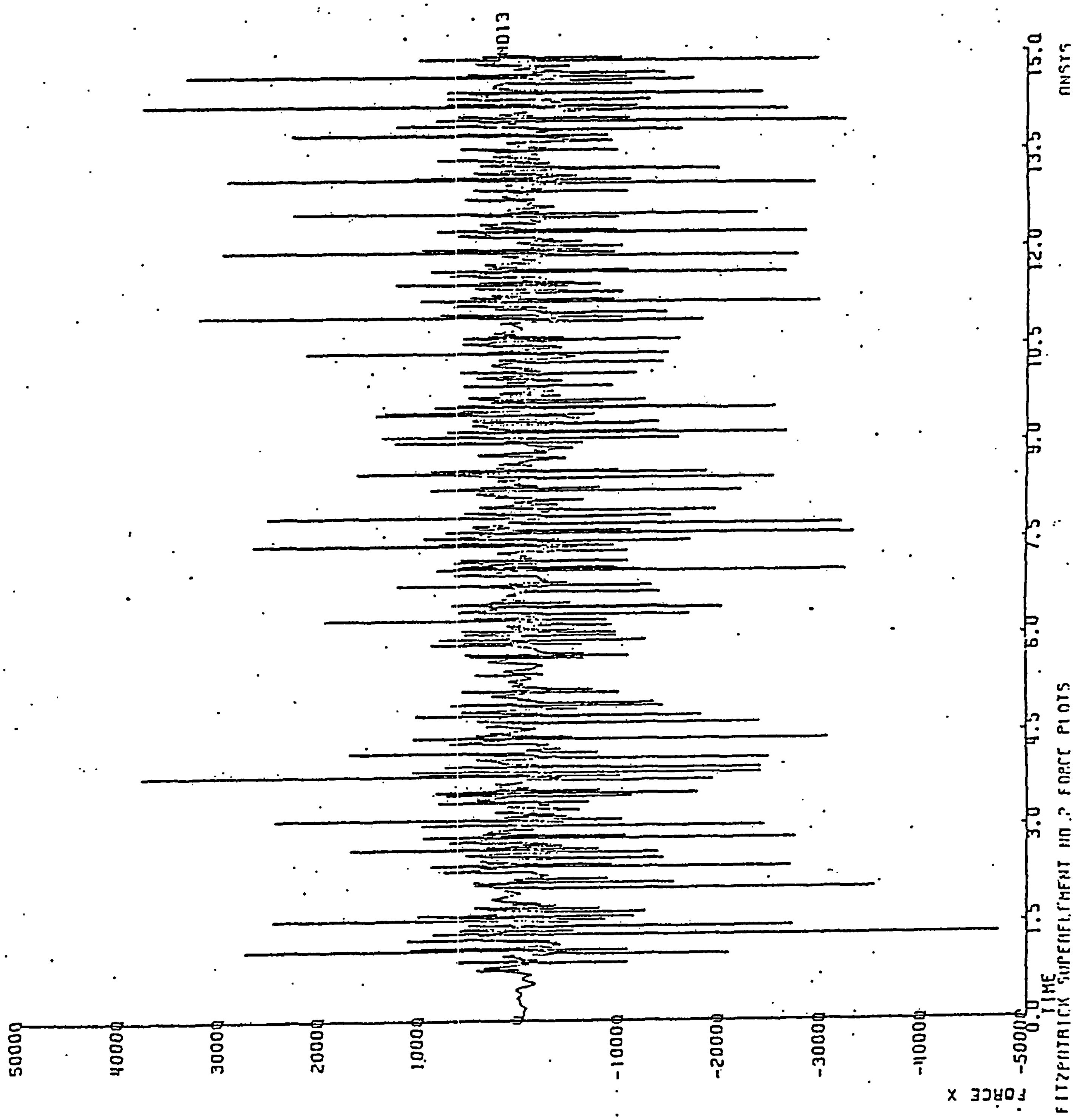


FIGURE 29 - Force X - Node 13

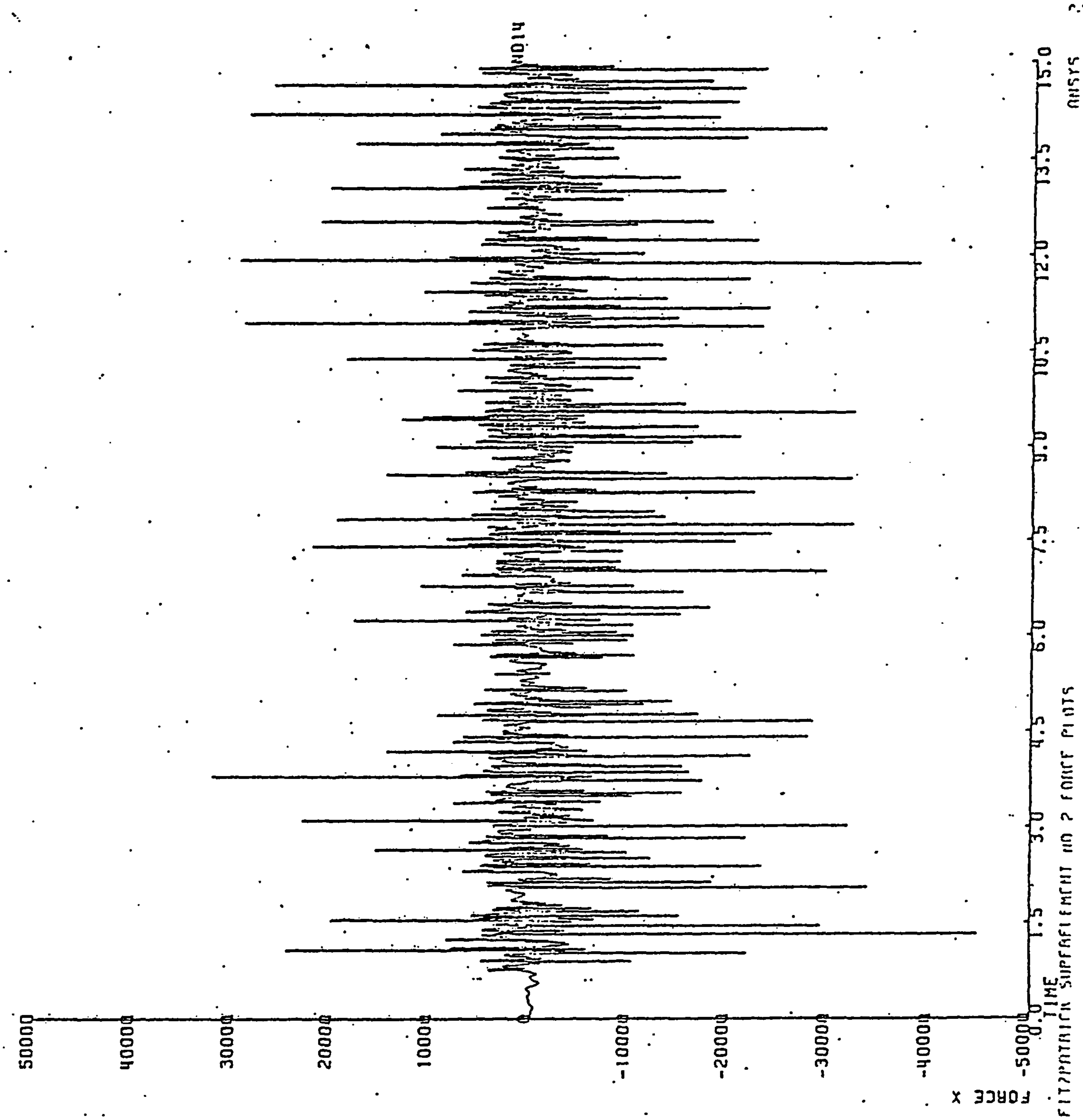


FIGURE 30 - Force X - Node 14

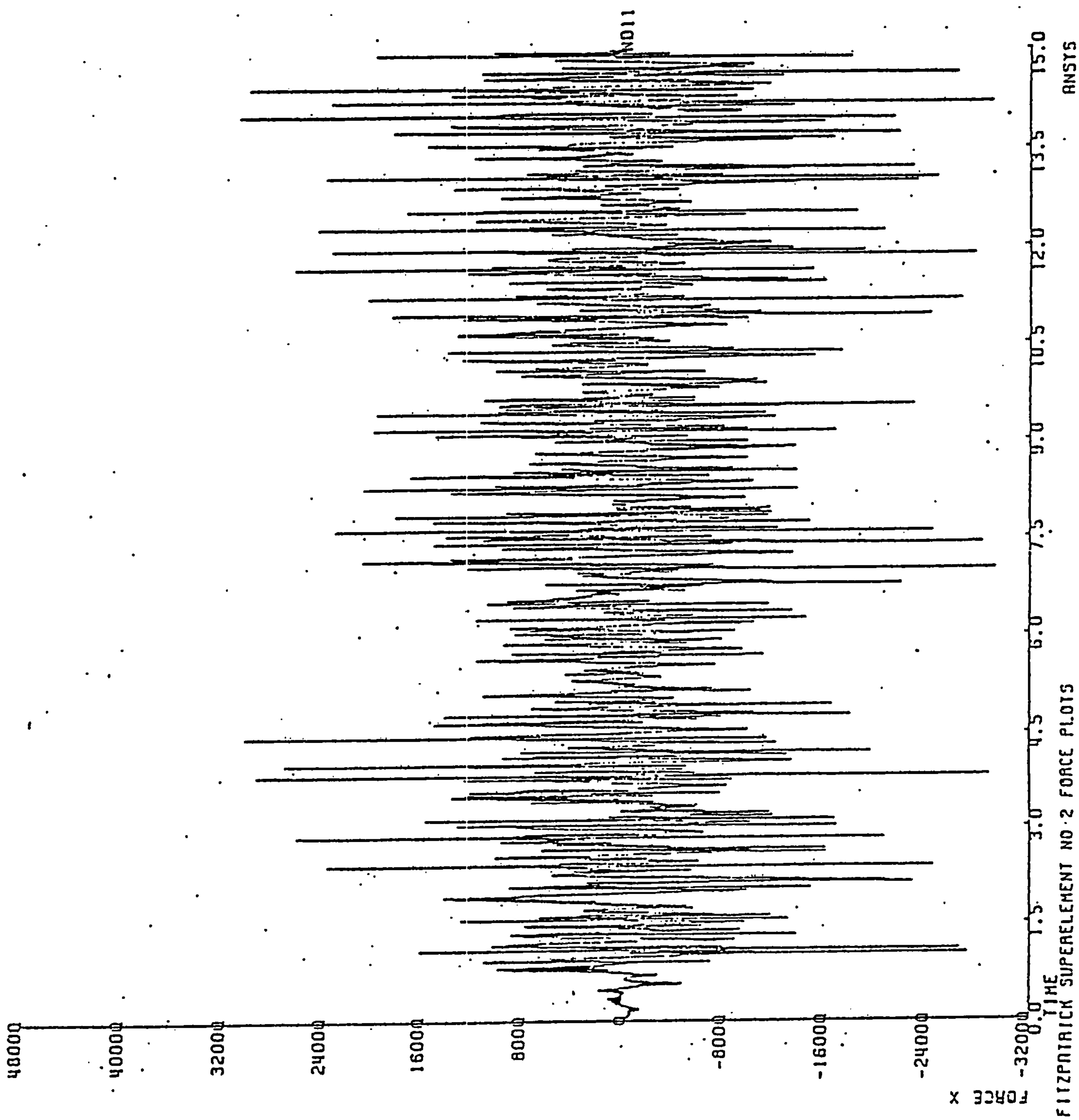


FIGURE 28 - Force X - Node 11

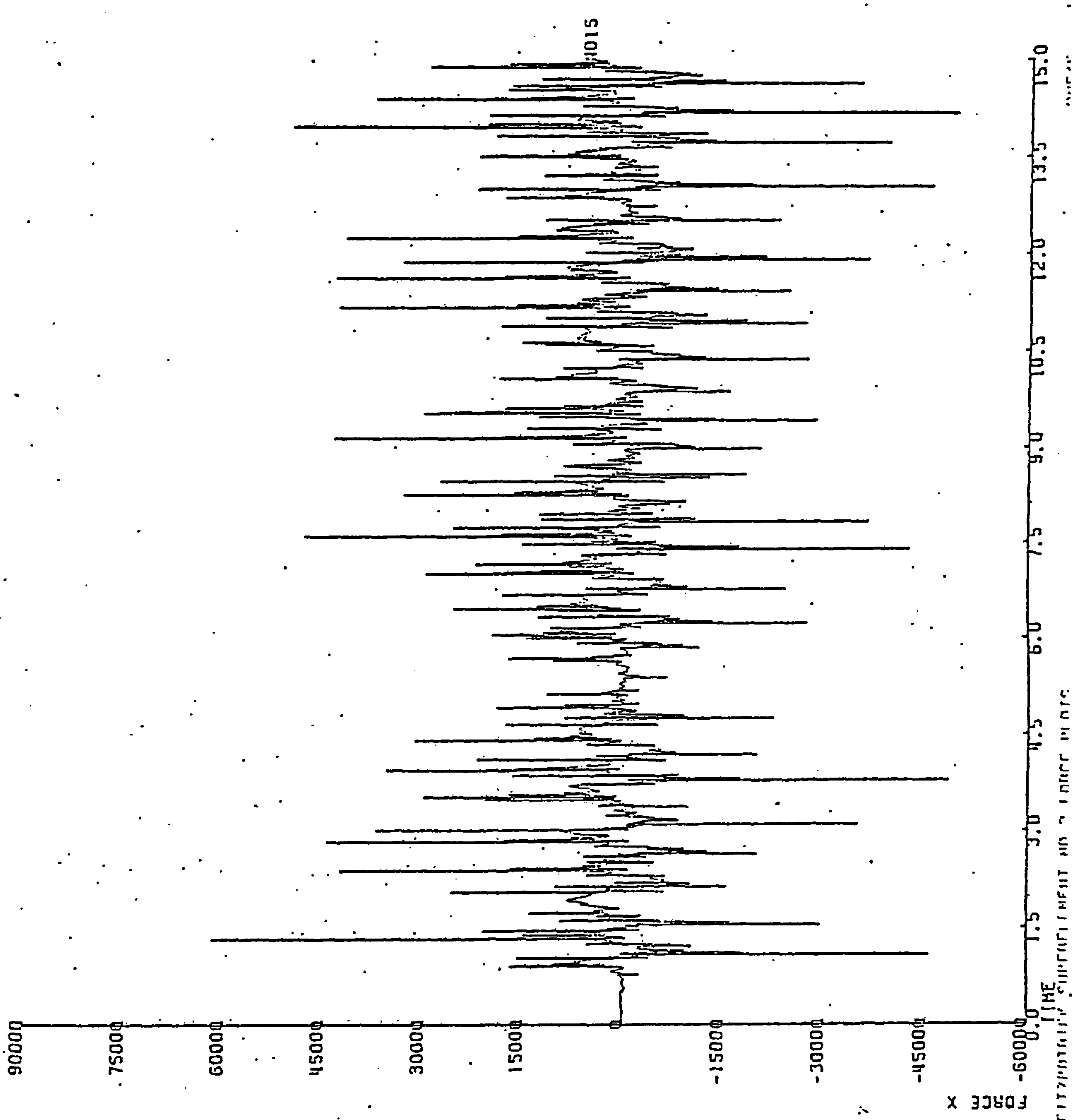


FIGURE 31 - Force X - Node 15

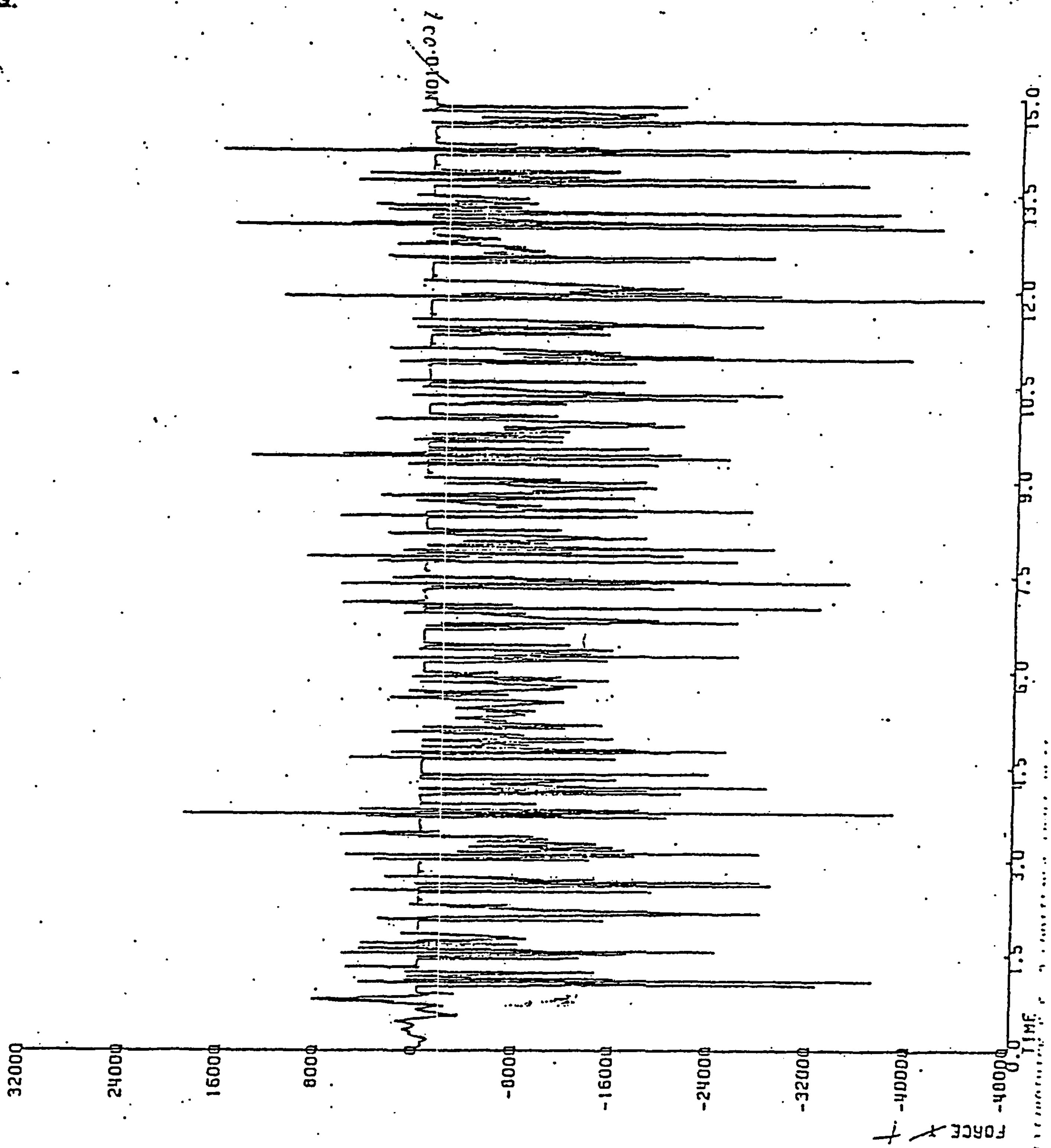


FIGURE 32 - Force X - Node 9

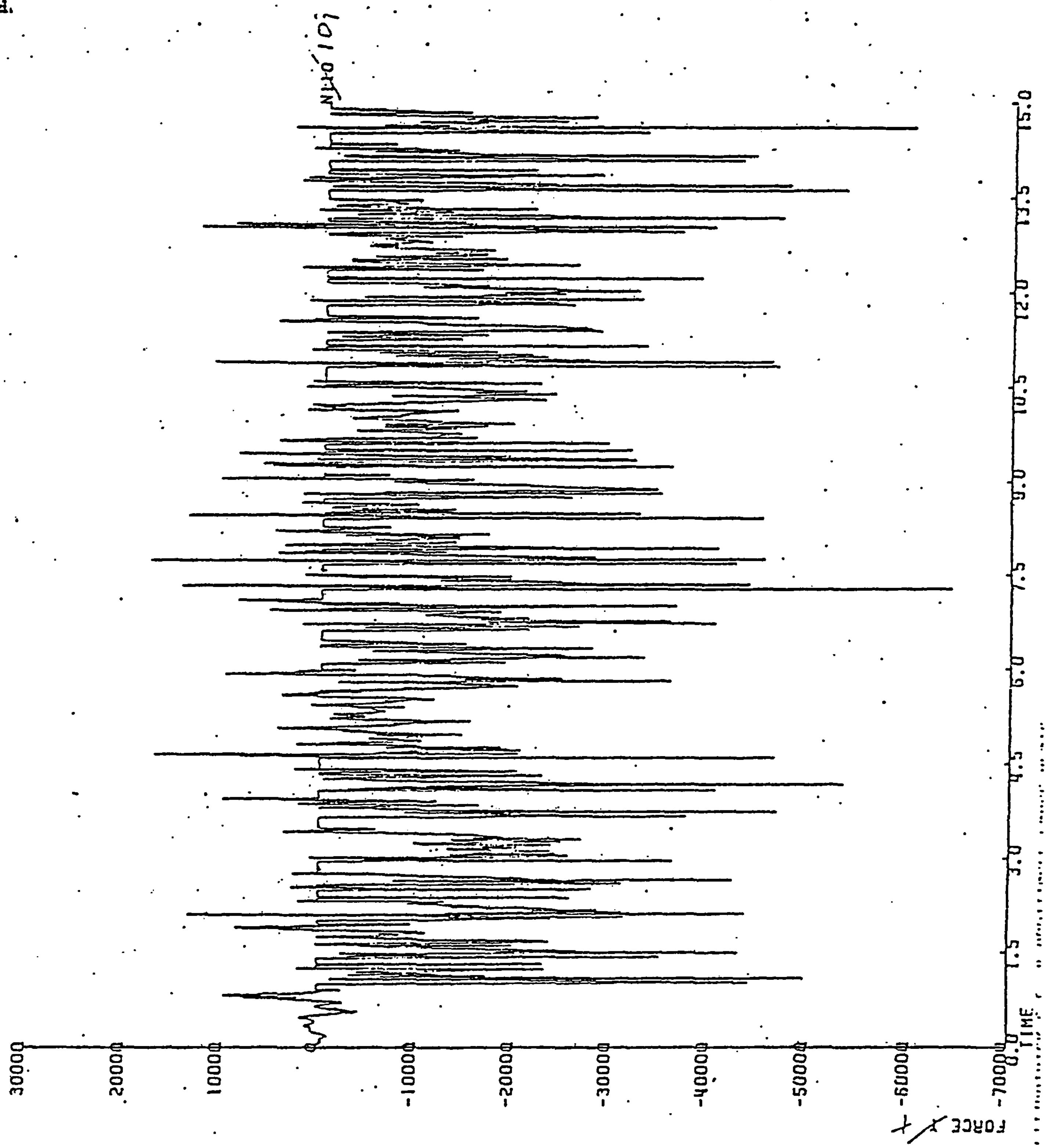


FIGURE 33 - Force X - Node 109

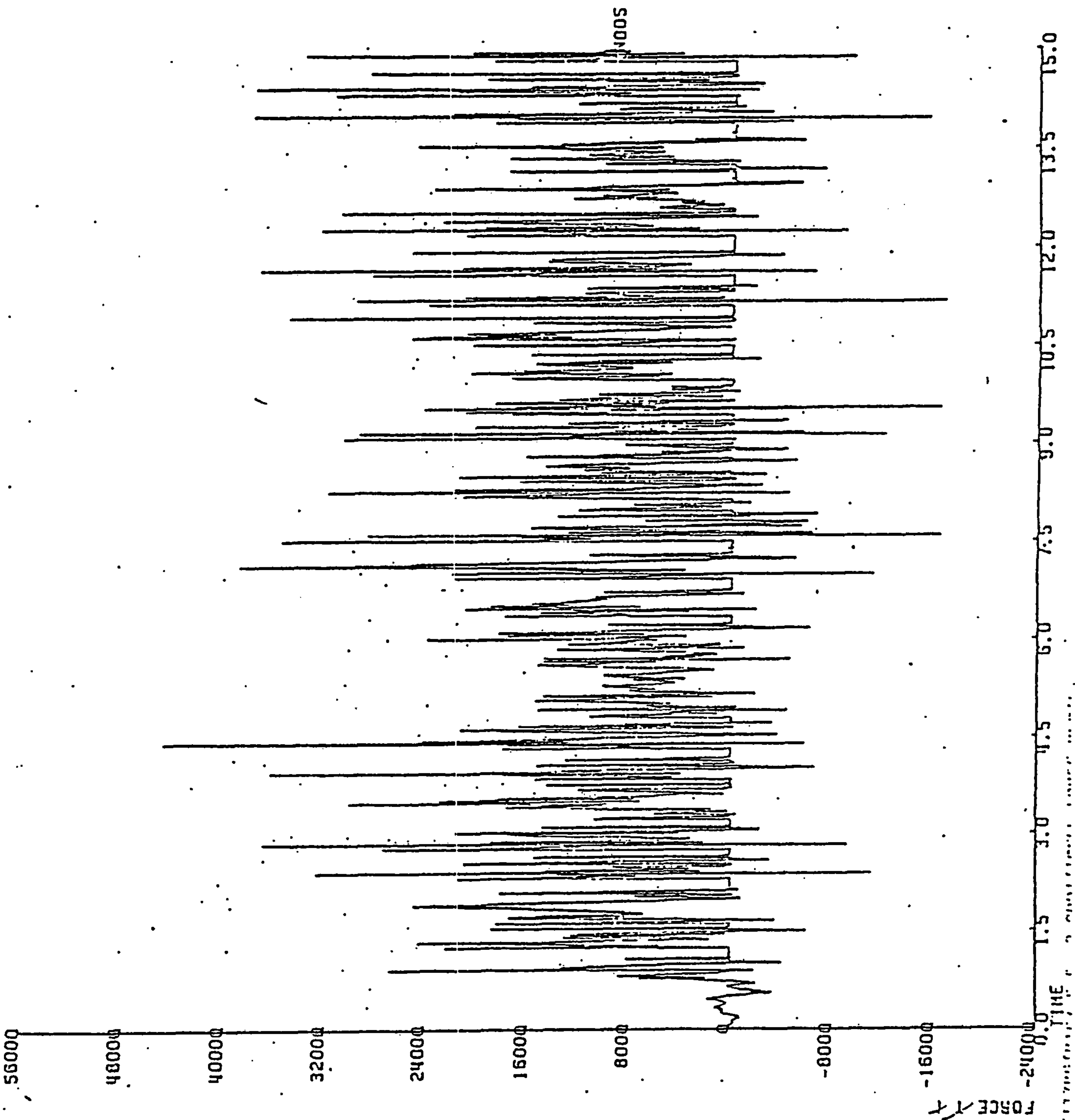


FIGURE 34 - Force X - Node 5

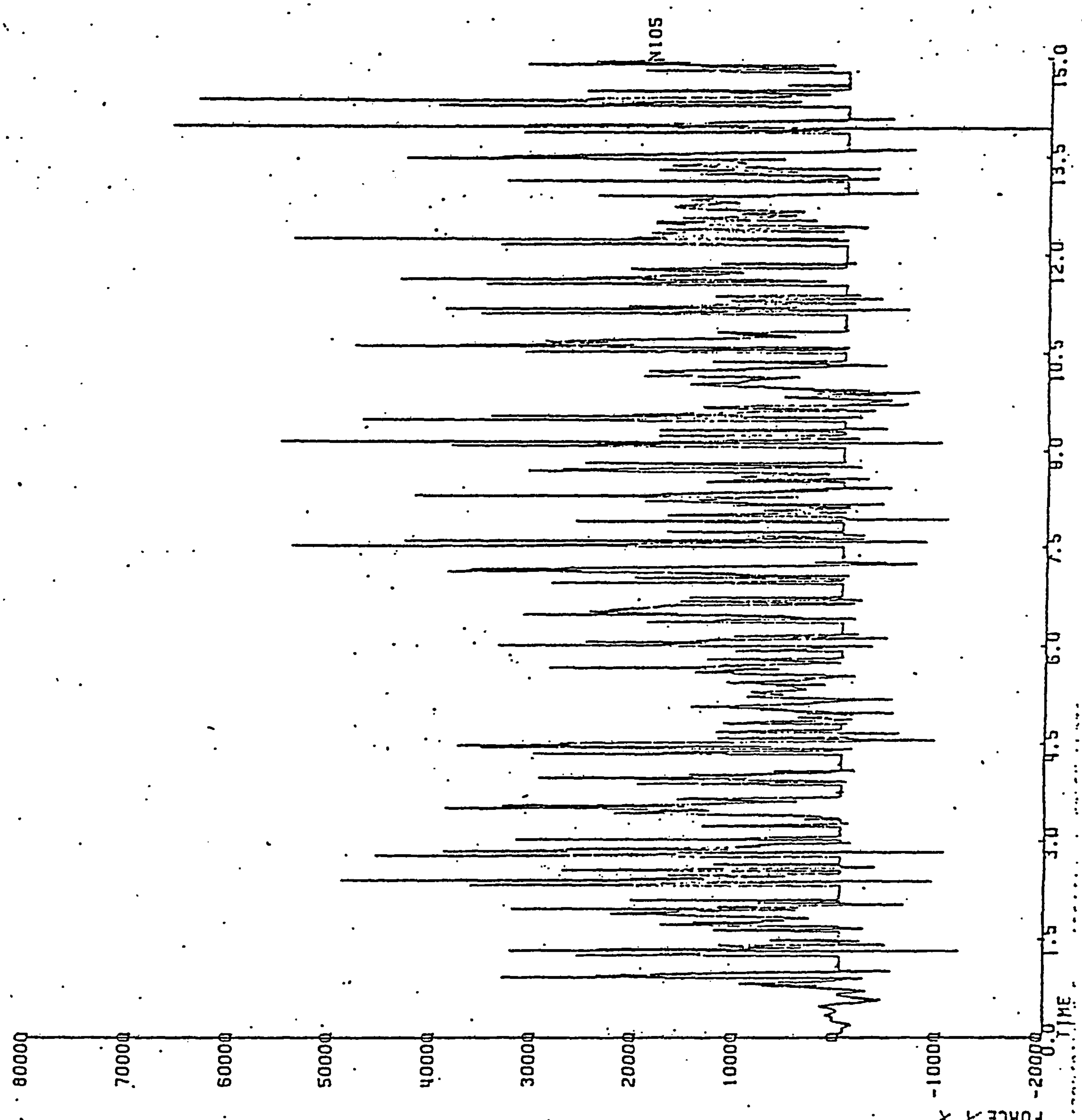


FIGURE 35 - Force X - Node 105

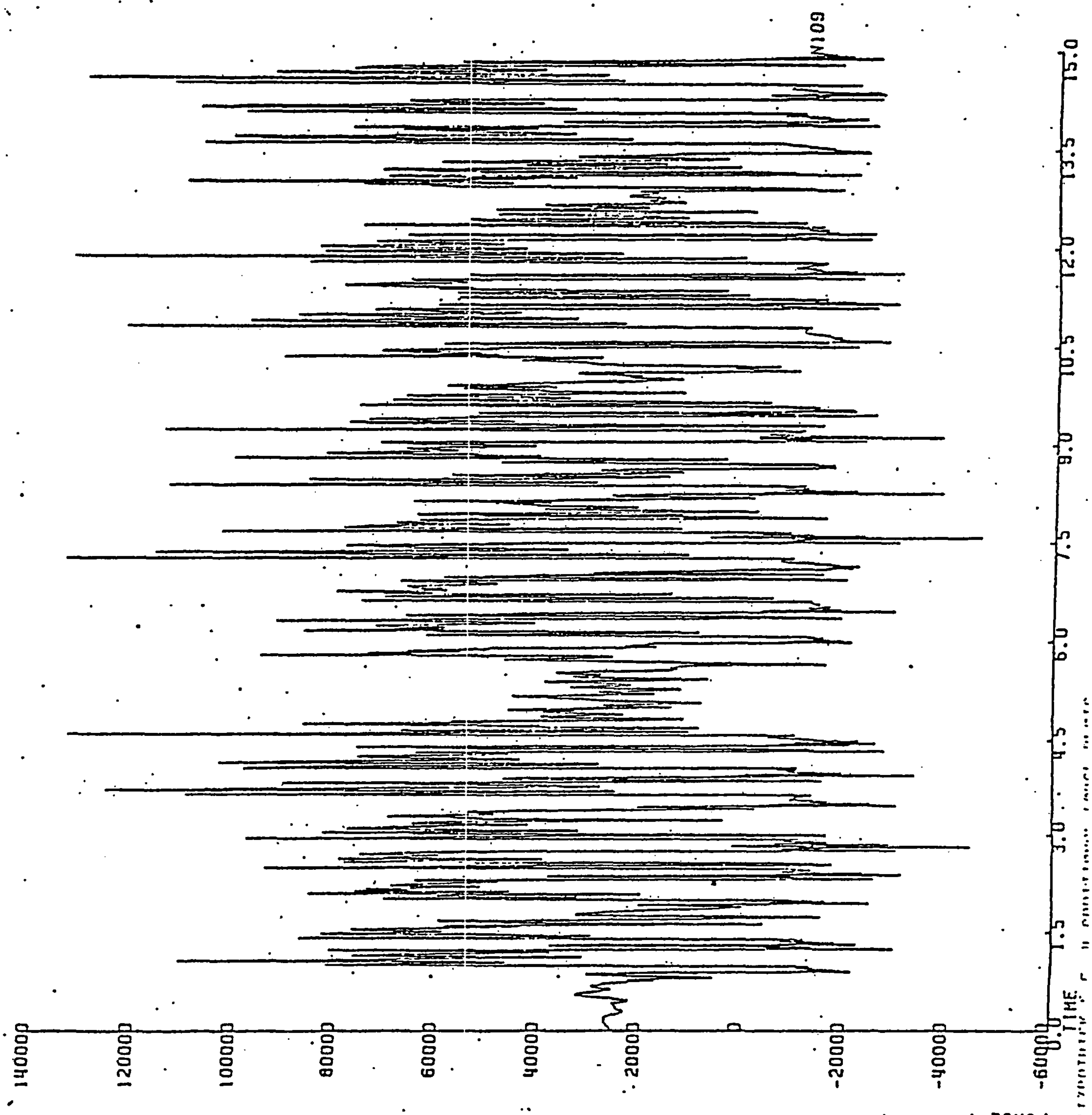


FIGURE 36 - Force Y - Node 109

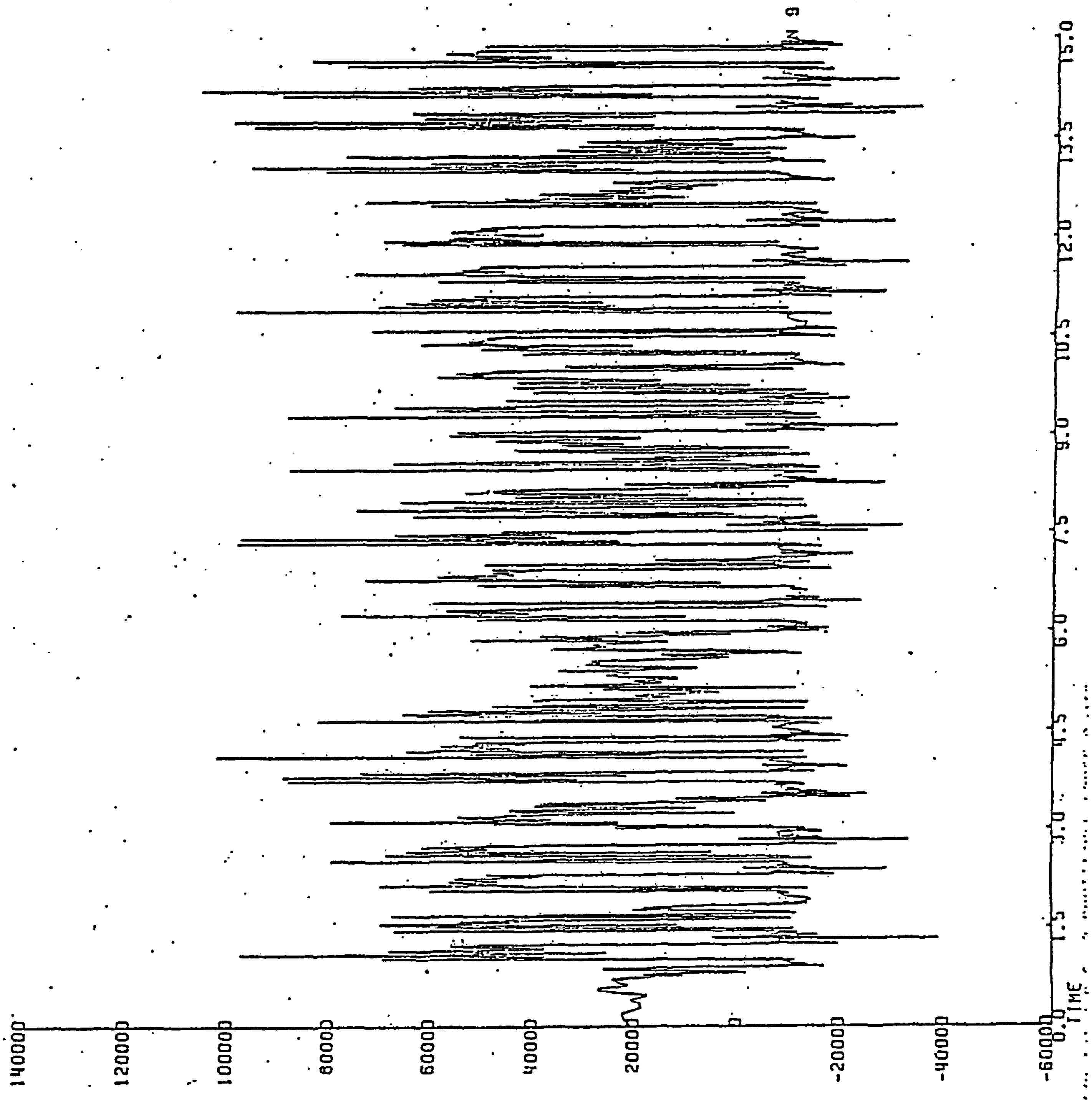


FIGURE 37 - Force Y - Node 9

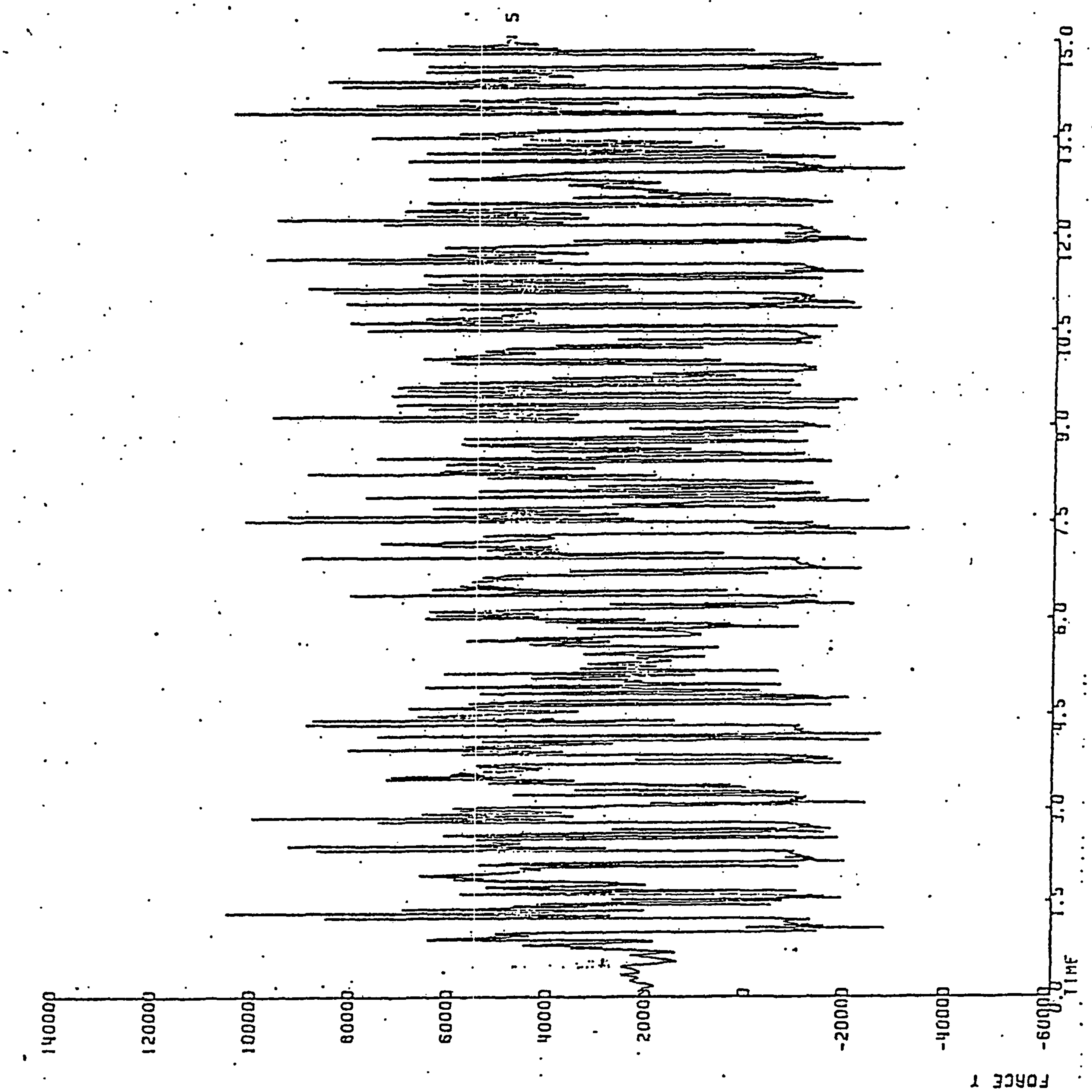


FIGURE 38 - Force Y - Node 5

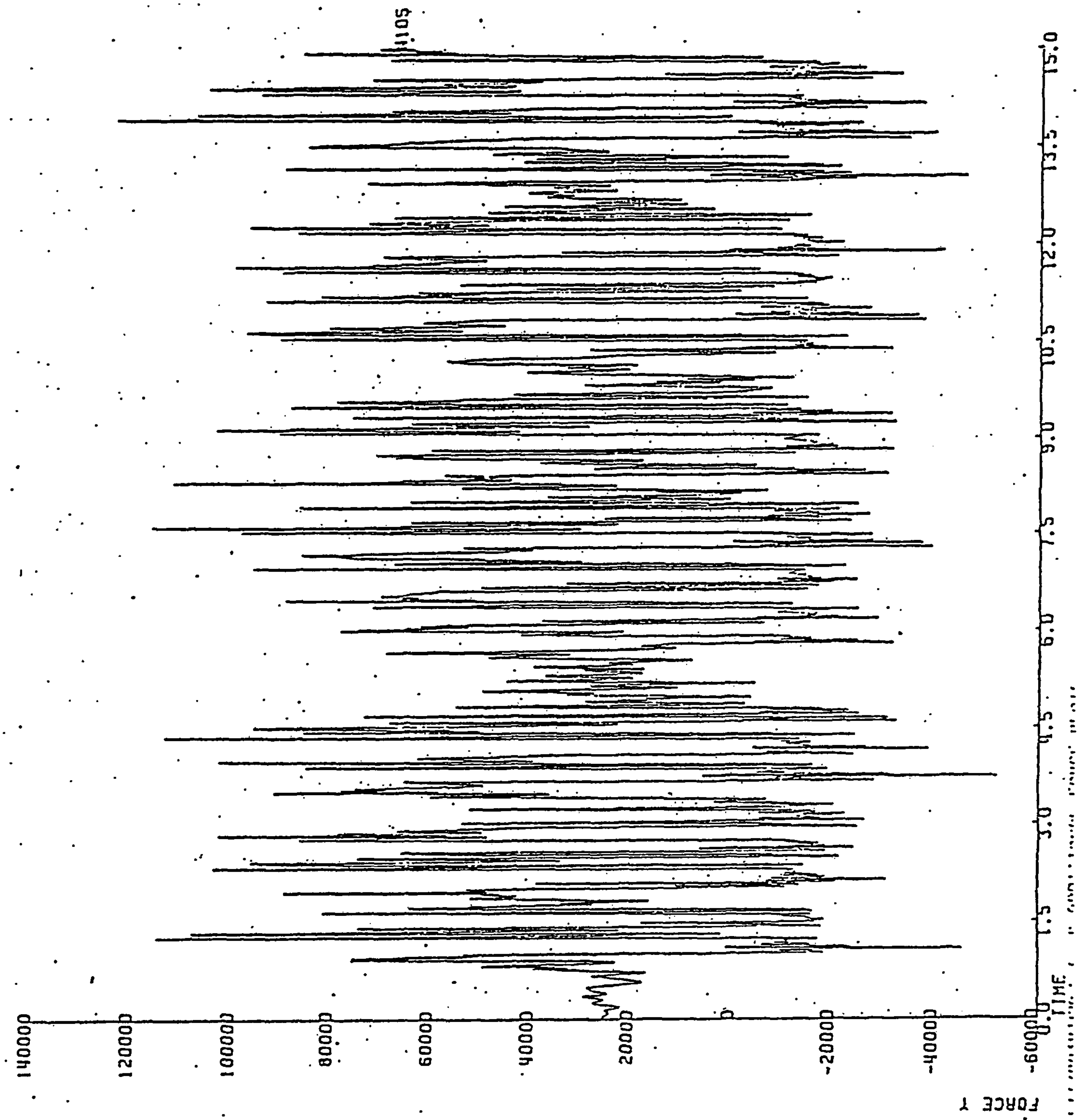


FIGURE 39 - Force Y - Node 105

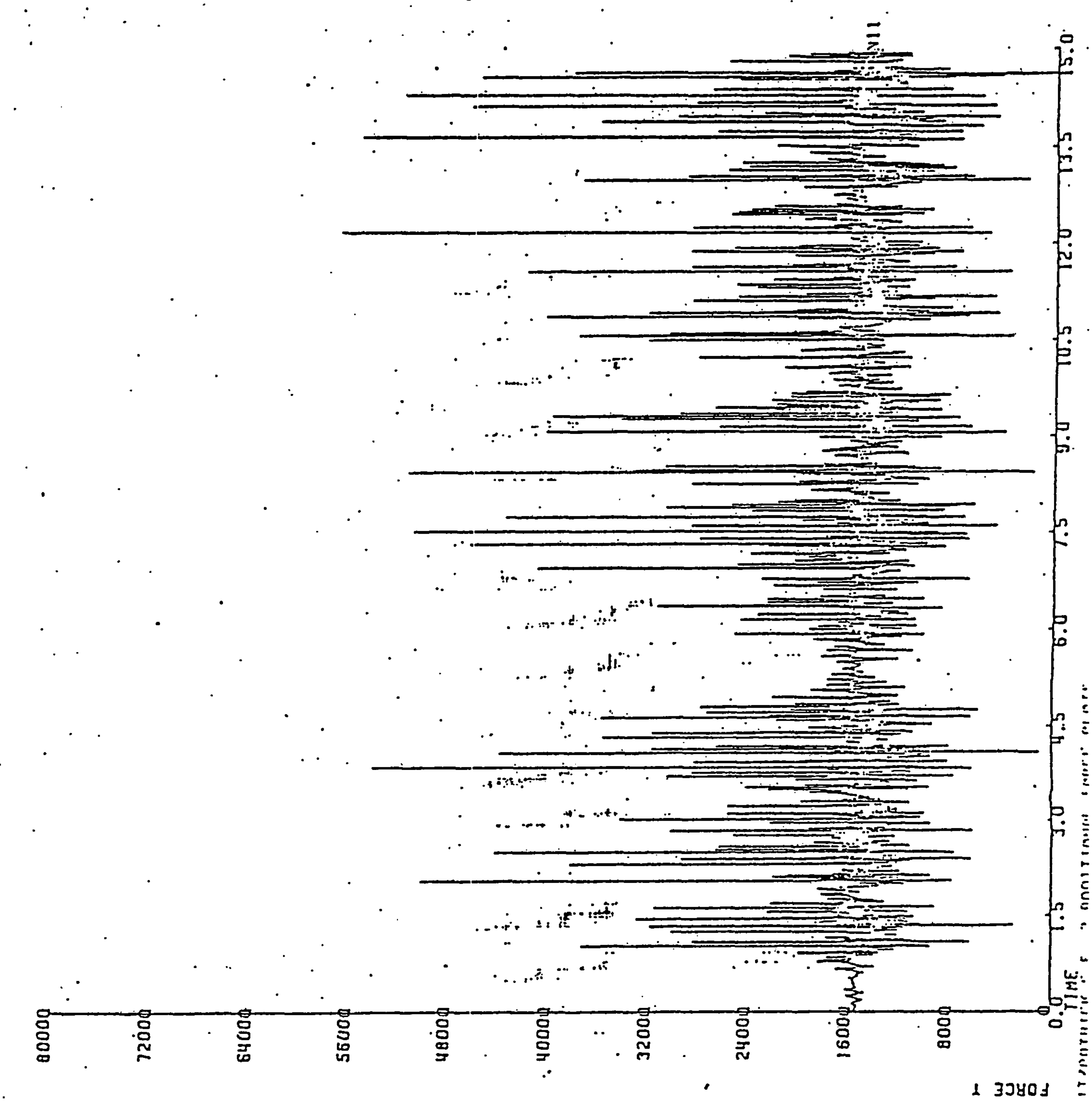


FIGURE 40 - Force Y - Node 11

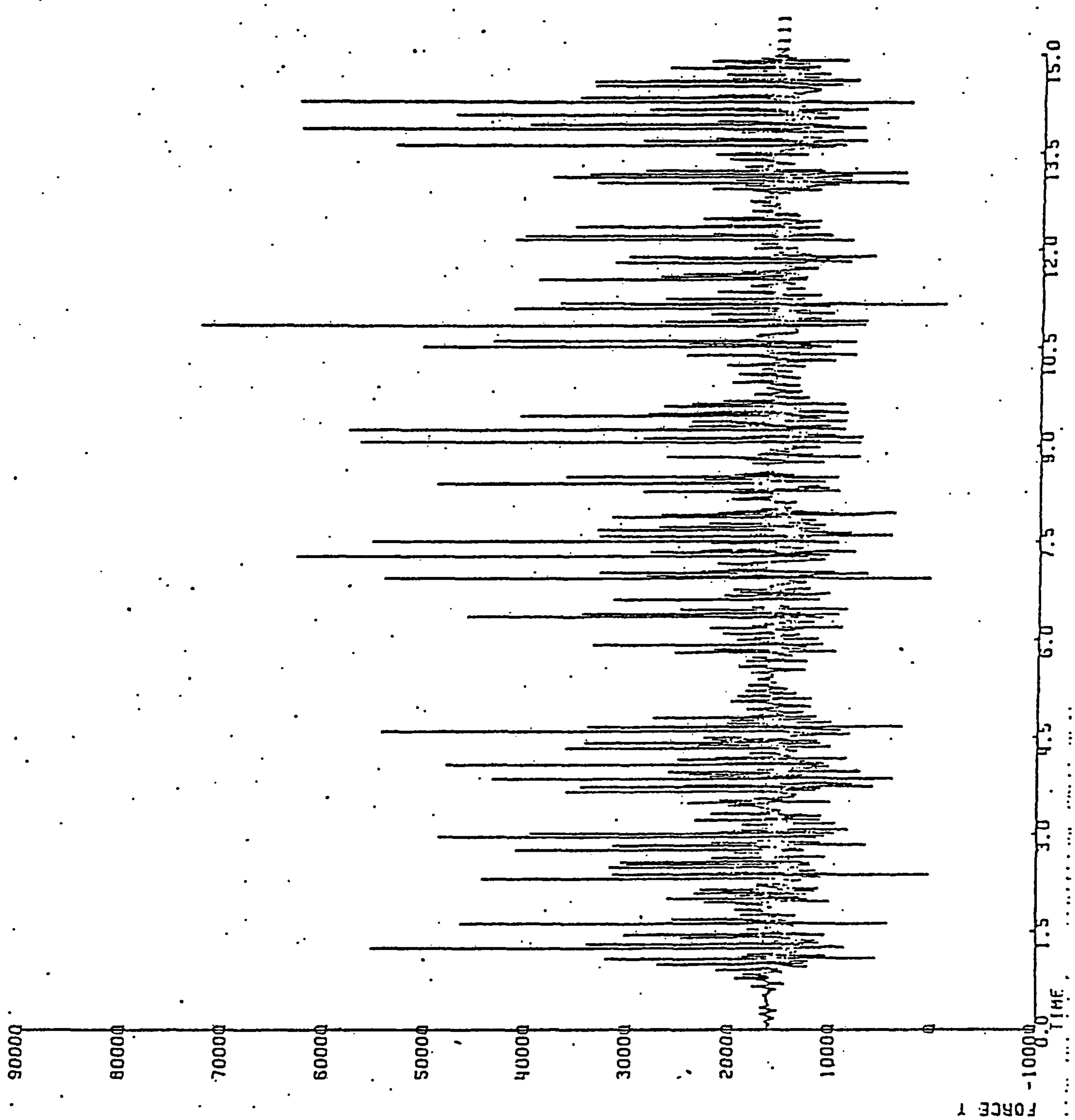


FIGURE 41 - Force Y - Node 111

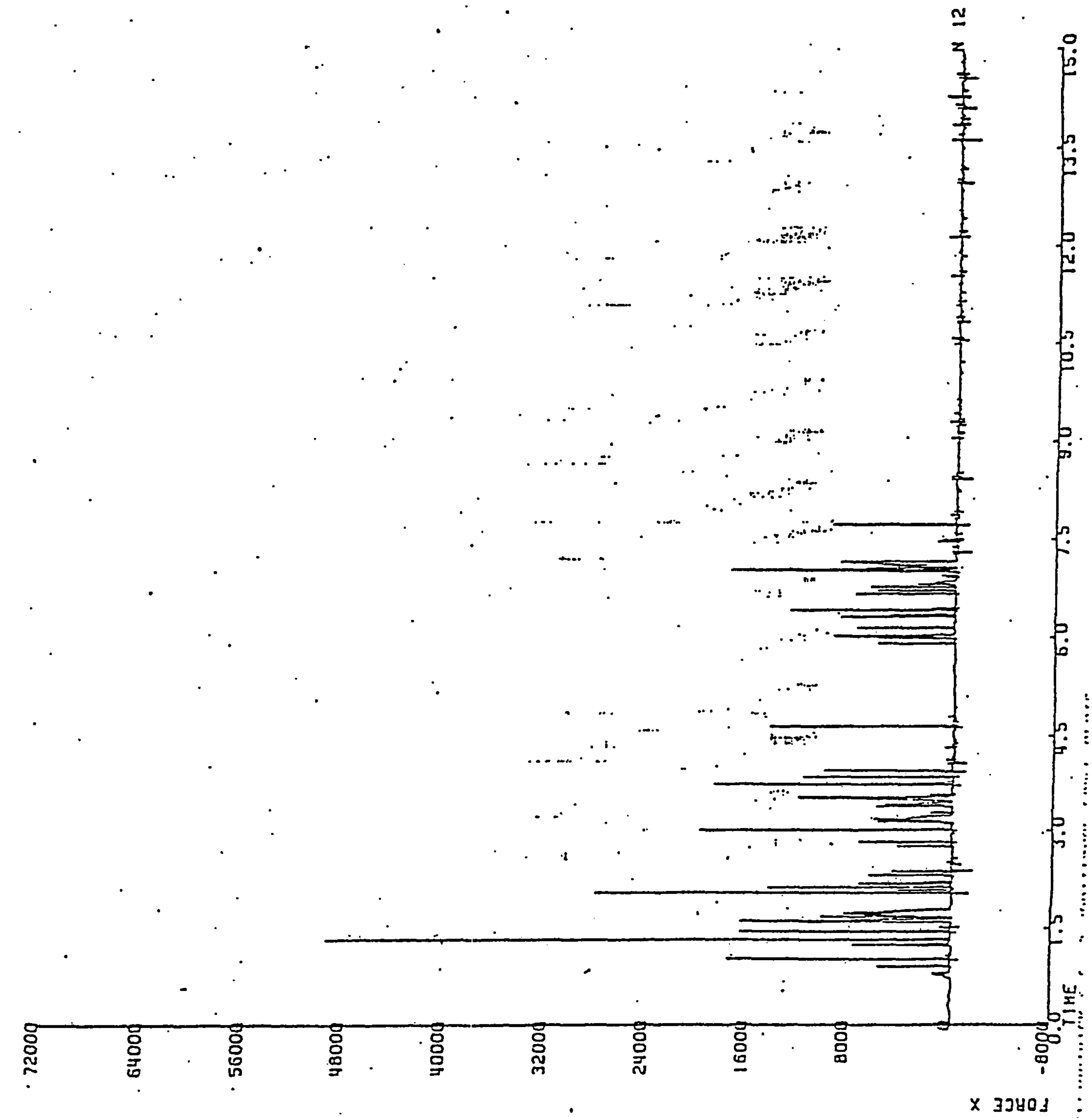


FIGURE 42 - Force X - Node 12

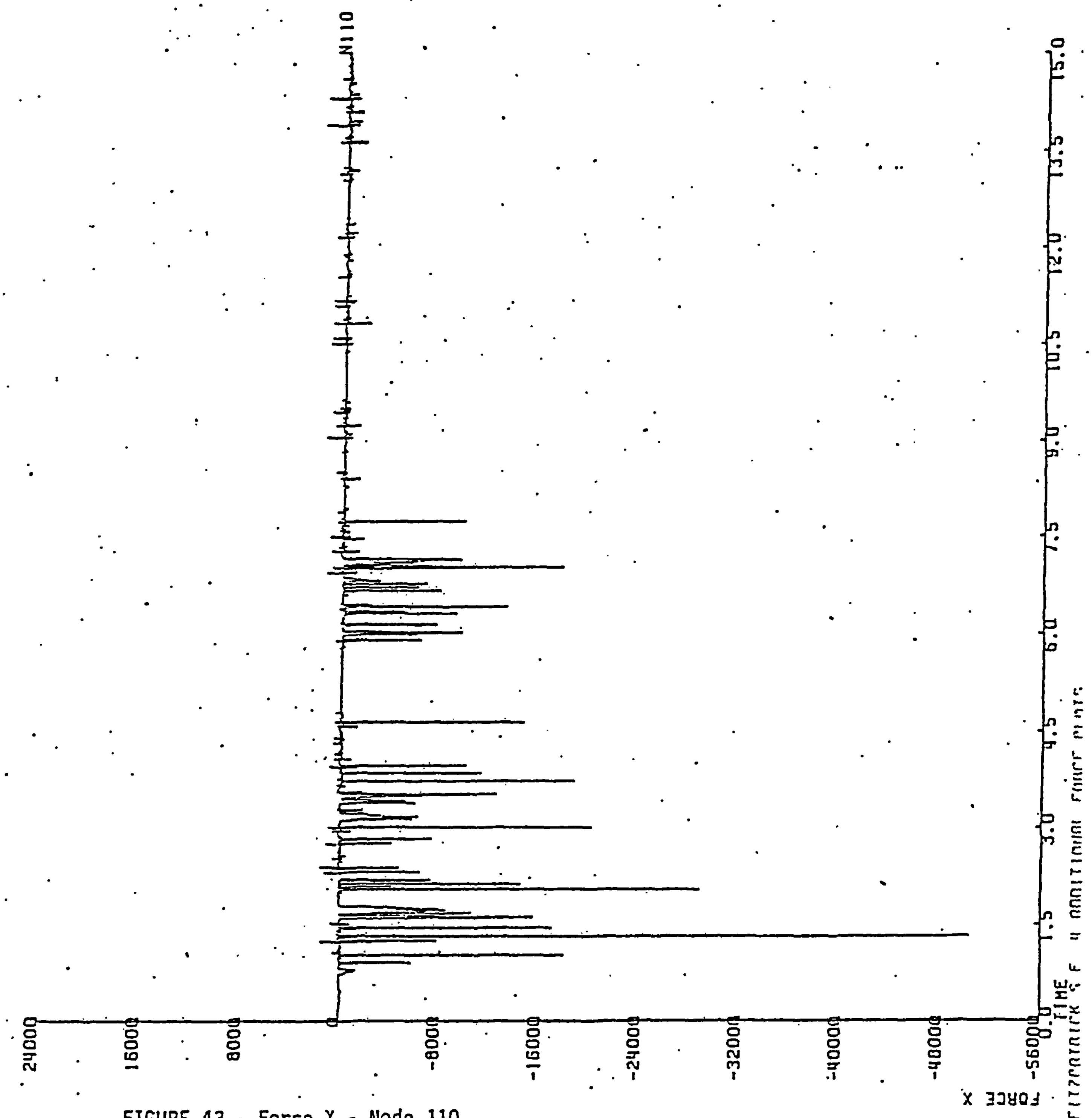


FIGURE 43 - Force X - Node 110

TABLE 1

DUANE-ARNOLD LOAD CASES - 8 x 11 RACK

Time	5 Fx	12 Fx	9 Fx	11 Fx	13 Fx	14 Fx	15 Fx	5 Fy	7 Fy	9 Fy	11 Fy
1.330 (336)	-14,108	43,074	+ 230	-13,639	-32,452	-44,713	61,689	-71,240	32,220	+19,938	19,078
1.334 (337)	-22,483	49,547	- 5,778	-10,391	-47,243	-18,302	54,649	-100,530	32,473	+35,955	32,098
3.734 (937)	+ 93	18,830	+10,270	- 8,469	-18,972	- 8,176	6,424	+ 3,860	51,997	-66,789	10,927
4.610 (1,156)	-14,732	88	- 58	5,407	2,016	982	6,296	-55,603	31,275	+ 8,611	15,713
7.738 (1,938)	- 3,085	170	+15,395	11,005	-17,569	-32,130	26,215	+ 3,449	37,554	-50,278	9,270
13.974 (3,497)	-38,282	192	- 144	31,221	6,113	1,150	- 250	-41,978	32,780	+ 965	8,230
14.190 (3,551)	- 142	28	+28,150	- 6,600	-11,152	- 7,365	- 2,919	+14,133	65,963	-98,836	18,733
4.426 (1,110)	-44,854	- 42	+ 117	30,547	7,883	4,435	1,915	-70,550	35,426	+14,816	20,303
7.290 (1,826)	- 8,290	- 290	+ 231	- 2,460	1,663	3,153	5,994	-54,359	27,099	+15,256	12,001
7.294 (1,827)	- 5,411	122	- 85	- 2,279	550	1,132	5,971	-47,156	27,431	+ 6,253	13,469
10.830 (2,711)	- 9,404	- 96	+ 80	1,588	857	1,278	5,697	-45,663	26,133	+ 9,323	10,204
11.878 (2,973)	+ 267	- 204	+44,935	-24,943	-26,532	- 4,699	11,176	+ 1,233	48,289	-58,600	9,074
12.162 (3,044)	- 6,091	902	+ 1,156	- 2,433	5,985	2,014	- 1,533	-54,307	27,488	-30,812	57,624
13.882 (3,474)	-19,082	- 590	+ 635	- 4,607	6,955	9,907	6,782	-106,800	56,529	+28,512	21,748
13.962 (3,494)	+ 7,647	- 308	+ 254	-21,184	- 7,994	2,096	19,489	-91,981	35,440	+27,401	29,135
14.186 (3,550)	- 509	40	- 4,370	23,990	268	- 6,195	-13,225	+17,928	65,021	-107,640	24,679
9.074 (2,272)	- 3,574	- 285	+ 228	- 4,865	2,869	3,360	2,268	-40,905	31,495	+ 5,333	4,074

TABLE 2

DUANE-ARNOLD LOAD CASES - 10 x 11 RACK

Time	105 Fx	110 Fx	109 Fx	111 Fx	113 Fx	114 Fx	115 Fx	105 Fy	107 Fy	109 Fy	111 Fy
1.330 (336)	-32,553	-43,222	+ 339	27,974	37,082	34,257	-23,878	-108,310	69,394	+16,806	22,146
1.334 (337)	-27,922	-50,200	+ 111	47,566	25,352	606	4,489	-96,329	72,859	+11,575	11,928
3.734 (937)	- 365	-18,551	+ 8,858	1,280	45,911	29,634	-66,768	+37,919	20,115	-85,545	27,529
4.610 (1,156)	10	0	+45,596	-17,139	-12,675	-10,148	- 5,624	+13,838	81,418	-111,140	15,922
7.738 (1,938)	-12,880	221	- 4,616	- 3,354	18,971	39,323	-37,665	-26,421	11,303	-12,745	27,878
13.974 (3,497)	-31,413	31	+ 31	15,736	- 656	- 1,820	18,091	-88,035	58,064	+14,289	15,711
14.190 (3,551)	- 138	154	+21,044	- 3,296	4,295	1,319	-23,378	+24,391	49,253	-95,951	22,334
4.426 (1,110)	-14,979	149	- 2,644	8,073	4,013	3,382	2,006	-56,750	52,383	-14,136	18,530
7.290 (1,826)	+ 84	37	+49,341	-12,972	-12,603	-13,997	- 9,890	+32,046	65,986	-134,120	36,127
7.294 (1,827)	- 300	419	+63,915	-33,182	-14,972	-10,878	- 5,003	+24,257	75,562	-112,790	13,008
10.830 (2,711)	- 6,996	- 1,924	+ 6,315	13,774	- 9,975	- 4,088	2,893	-39,180	33,641	-67,869	73,450
11.878 (2,973)	- 9,974	- 29	- 1,831	7,364	19,139	- 632	-14,073	-11,619	36,631	-35,391	10,397
12.162 (3,044)	-13,054	- 529	+ 502	- 6,464	6,482	9,268	3,795	-61,980	32,413	+20,645	8,938
13.882 (3,474)	-32,301	99	+ 1,191	- 2,575	11,270	13,101	9,216	-124,310	68,214	+24,433	31,700
13.962 (3,494)	-67,043	58	+ 89	39,317	13,807	9,053	4,719	-108,760	72,587	+16,875	19,333
14.186 (3,550)	- 146	166	+22,291	- 1,064	1,178	- 2,217	-20,209	+24,200	56,555	-102,420	21,697
9.074 (2,272)	-22,846	- 90	- 833	1,209	6,012	9,385	7,162	-85,305	48,794	+19,087	17,449

APPENDIX

DIGITIZED TIME HISTORIES

MAXIMUM GROUND ACCELERATION = .500 G'S

MAXIMUM GROUND VELOCITY = 10.097 IN./SEC.

MAXIMUM GROUND DISPLACEMENT = 1.029 IN.

SIMULATED GROUND ACCELERATION

.0007	.0020	.0022	.0016	-.0003	-.0026	-.0066	-.0092	-.0124	-.0135	-.0136	-.0128	-.0136	-.0143	-.0168
-.0237	-.0274	-.0309	-.0322	-.0297	-.0244	-.0140	-.0072	.0053	.0131	.0202	.0248	.0224	.0248	.0273
.0299	.0328	.0418	.0406	.0433	.0374	.0327	.0241	.0165	.0133	.0127	.0092	.0211	.0252	.0365
.0506	.0538	.0555	.0521	.0389	.0168	-.0120	-.0360	-.0620	-.0900	-.1076	-.1158	-.1155	-.1015	-.0964
-.0759	-.0614	-.0379	-.0185	-.0099	-.0051	-.0092	-.0237	-.0401	-.0597	-.0695	-.0695	-.0410	-.0114	.0285
.0947	.1438	.2022	.2474	.2913	.3043	.2905	.2706	.2194	.1858	.1381	.0824	.0323	.0101	.0015
.0105	.0139	.0253	.0251	.0018	-.0307	-.0676	-.1119	-.1550	-.2042	-.2459	-.2929	-.3360	-.3475	-.3554
-.3182	-.2786	-.2196	-.1514	-.0936	-.0360	.0267	.0908	.1493	.2034	.2442	.2526	.2375	.2242	.1730
.1451	.1120	.0915	.0770	.0633	.0587	.0466	.0364	.0237	-.0045	-.0473	-.0678	-.1013	-.1439	-.1548
-.1762	-.1691	-.1430	-.1128	-.0660	-.0452	-.0127	-.0022	-.0005	-.0204	-.0424	-.0766	-.1247	-.1435	-.1648
-.1409	-.1130	-.0741	-.0053	.0450	.0967	.1399	.1527	.1656	.1412	.1162	.0722	.0166	-.0414	-.0861
-.1009	-.1032	-.0824	-.0462	-.0255	-.0096	-.0103	-.0108	-.0138	-.0347	-.0520	-.0660	-.0792	-.0899	-.0796
-.0631	-.0328	.0178	.0856	.1494	.2137	.2771	.3299	.3678	.3971	.4072	.3769	.3266	.2469	.1452
.0253	-.0838	-.1906	-.2672	-.3110	-.3428	-.3114	-.2584	-.1937	-.0991	-.0186	.0582	.1189	.1448	.1338
.0867	.0479	-.0269	-.0931	-.1818	-.2304	-.2754	-.2801	-.2702	-.2222	-.1637	-.0780	-.0128	.0699	.1208
.1611	.1822	.1895	.2007	.1852	.1903	.1631	.1456	.1267	.0702	.0289	-.0060	-.0400	-.0685	-.0769
-.0959	-.1017	-.1157	-.1249	-.1158	-.0979	-.0660	-.0214	.0055	.0601	.0932	.1176	.1273	.1313	.1092
.0851	.0438	-.0039	-.0526	-.1143	-.1672	-.2143	-.2405	-.2643	-.2516	-.2088	-.1522	-.0732	.0060	.0946
.1772	.2430	.2747	.2845	.2861	.2609	.2409	.2177	.1948	.1646	.1247	.0820	.0414	.0028	-.0215
-.0344	-.0443	-.0606	-.0586	-.0713	-.0693	-.0925	-.0989	-.0932	-.0909	-.0811	-.0344	-.0159	.0284	.0621
.0664	.0821	.0600	.0325	-.0055	-.0492	-.0799	-.0968	-.0923	-.0825	-.0584	-.0314	-.0003	.0219	.0371
.0377	.0269	-.0031	-.0341	-.0736	-.1117	-.1507	-.1910	-.2009	-.2169	-.2274	-.2283	-.2048	-.2054	-.1821
-.1580	-.1380	-.1192	-.1061	-.0930	-.0638	-.0368	.0013	.0540	.0960	.1732	.2293	.2724	.3209	.3487
.3520	.3473	.3196	.2779	.2414	.1935	.1479	.1145	.0769	.0493	.0184	.0085	-.0219	-.0459	-.0816
-.1149	-.1544	-.1889	-.2187	-.2367	-.2387	-.2464	-.2347	-.2067	-.1827	-.1454	-.0908	-.0435	.0308	.1021
.1663	.2208	.2351	.2313	.2119	.1735	.1363	.1130	.0932	.0687	.0480	.0209	.0063	.0003	.0038
.0209	.0637	.1049	.1273	.1389	.1285	.1059	.0673	.0233	-.0348	-.0923	-.1573	-.2141	-.2542	-.2690
-.2549	-.2141	-.1500	-.0932	-.0350	.0101	.0262	.0165	-.0275	-.0839	-.1383	-.2183	-.2484	-.2496	-.2427
-.1849	-.1193	-.0154	.0902	.1849	.2400	.2970	.2811	.2456	.1713	.0925	.0133	-.0308	-.0987	-.1220
-.1240	-.1038	-.0705	-.0178	.0468	.1236	.1947	.2540	.2965	.3108	.3067	.2966	.2324	.1524	.0456
-.0786	-.2170	-.3341	-.4187	-.4708	-.4533	-.3867	-.2744	-.1420	.0017	.1287	.2329	.2925	.3707	.3295
.2698	.2278	.1423	.0552	-.0172	-.0898	-.1319	-.1525	-.1390	-.1183	-.0542	.0046	.0736	.1145	.1537
.1535	.1405	.1067	.0601	.0138	-.0341	-.0704	-.1125	-.1385	-.1555	-.1403	-.1265	-.1094	-.1006	-.1075
-.1101	-.1307	-.1529	-.1462	-.1312	-.0883	-.0311	.0362	.1145	.1750	.2223	.2366	.2283	.1868	.1165
.0612	.0072	-.0502	-.0738	-.1251	-.1526	-.1851	-.1931	-.1770	-.1434	-.0878	-.0327	.0142	.0511	.0911
.0897	.1019	.1011	.0976	.0832	.0656	.0316	-.0001	-.0214	-.0441	-.0460	-.0393	-.0193	.0085	.0408
.0018	.0896	.1100	.1025	.1029	.0966	.0634	.0303	-.0076	-.0461	-.0990	-.1401	-.1744	-.1616	-.1381
-.0869	.0171	.0929	.1731	.2380	.2675	.2825	.2570	.2108	.1571	.0808	.0042	-.0713	-.1373	-.1774
-.1905	-.1945	-.1916	-.1818	-.1846	-.1786	-.1735	-.1665	-.1354	-.1152	-.0708	-.0290	.0196	.0534	.0840
.0921	.0826	.0748	.0623	.0538	.0827	.0741	.1084	.1077	.1232	.1168	.1197	.1067	.0938	.0618
.0303	.0007	-.0164	-.0537	-.0549	-.0496	-.0340	-.0257	-.0099	-.0085	-.0093	-.0192	-.0604	-.0083	-.1427
-.1747	-.1935	-.2009	-.1907	-.1763	-.1403	-.1023	-.0455	-.0010	.0491	.0764	.1014	.0883	.0991	.0786
.0774	.0506	.0399	.0077	-.0097	-.0181	-.0239	-.0134	.0057	.0101	.0344	.0384	.0691	.0533	.0594

.0416	.0454	.0349	.0295	.0316	.0463	.0603	.0623	.0008	.0964	.1118	.1007	.1004	.0876	.0682
.0359	.0026	-.0196	-.0379	-.0509	-.0582	-.0442	-.0355	-.0392	-.0216	-.0372	-.0419	-.0553	-.0675	-.0941
-.1225	-.1467	-.1666	-.1913	-.1817	-.1667	-.1438	-.0962	-.0660	-.0173	.0225	.0484	.0764	.1033	.1100
.1324	.1493	.1382	.1372	.0919	.0463	-.0101	-.0898	-.1612	-.2226	-.2609	-.2740	-.2482	-.2169	-.1400
-.0584	.0493	.1374	.2350	.3092	.3686	.4217	.4531	.5000	.4542	.4324	.3778	.2946	.2000	.0730
-.0571	-.1816	-.3029	-.3976	-.4545	-.4684	-.4614	-.4022	-.3206	-.2287	-.1192	-.0166	.0927	.1642	.2065
.2424	.2170	.1679	.0889	.0036	-.0896	-.1431	-.1806	-.1749	-.1490	-.0861	-.0043	.0777	.1736	.2524
.3258	.3588	.3707	.3504	.2851	.2180	.1074	-.0072	-.0990	-.2060	-.2742	-.3236	-.3436	-.3312	-.2998
-.2359	-.1672	-.0816	.0045	.0591	.0834	.0901	.0570	.0065	-.0535	-.1137	-.1474	-.1551	-.1141	-.0508
.0258	.1162	.1927	.2452	.2781	.2679	.2254	.1594	.0430	-.0681	-.1850	-.2893	-.3473	-.3700	-.3411
-.2772	-.2063	-.1233	-.0379	.0132	.0658	.0729	.0623	.0279	-.0200	-.0734	-.1357	-.1668	-.1915	-.1974
-.1618	-.1119	-.0353	.0479	.1553	.2214	.2735	.3084	.3079	.2908	.2586	.2311	.2007	.1834	.1603
.1626	.1565	.1452	.1305	.0901	.0377	-.0406	-.1231	-.2024	-.2802	-.3235	-.3358	-.3284	-.2885	-.2093
-.1557	-.0502	.0161	.0931	.1411	.1985	.2263	.2423	.2340	.2195	.1838	.1513	.0997	.0575	.0282
-.0066	-.0178	-.0303	-.0177	.0002	.0278	.0508	.0998	.1271	.1469	.1579	.1286	.1067	.0411	-.0160
-.0751	-.1443	-.1983	-.2243	-.2245	-.1819	-.1112	-.0243	.0574	.1287	.1612	.1646	.1368	.0728	-.0059
-.0924	-.1719	-.2492	-.3105	-.3393	-.3414	-.3363	-.2927	-.2359	-.1775	-.1244	-.0738	-.0369	.0186	.0563
.1135	.1629	.1997	.2375	.2673	.2923	.3007	.2808	.2706	.2334	.1706	.1226	.0349	-.0448	-.1464
-.2262	-.2963	-.3236	-.3329	-.2941	-.2347	-.1635	-.0619	.0430	.1150	.1803	.2156	.2035	.1680	.0900
.0310	-.0590	-.1131	-.1536	-.1889	-.1964	-.1868	-.1479	-.0687	.0188	.1077	.1959	.2672	.3206	.3543
.3509	.3344	.2957	.2197	.1366	.0327	-.0483	-.1276	-.1722	-.2120	-.2097	-.1966	-.1756	-.1241	-.0843
-.0374	-.0025	.0157	.0228	.0441	.0643	.0820	.1027	.1049	.1059	.0805	.0629	.0221	.0083	-.0038
-.0166	-.0343	-.0346	-.0538	-.0659	-.0926	-.1337	-.1535	-.1613	-.1070	-.1685	-.1609	-.1395	-.1159	-.0921
-.0722	-.0588	-.0425	-.0369	-.0087	-.0007	.0454	.0708	.0851	.1090	.1163	.1247	.1174	.1114	.0802
.0765	.0582	.0629	.0346	.0273	-.0028	-.0349	-.0570	-.0826	-.0814	-.0718	-.0413	.0074	.0420	.0916
.1208	.1595	.1760	.1744	.1545	.1033	.0313	-.0693	-.1696	-.2512	-.3148	-.3416	-.3288	-.2962	-.2304
-.1666	-.1021	-.0452	-.0090	.0134	.0305	.0473	.0539	.0640	.0831	.0864	.0902	.0852	.0800	.0685
.0650	.0561	.0507	.0380	.0111	-.0006	-.0189	-.0048	.0406	.0795	.1326	.1891	.2314	.2747	.2826
.2965	.2962	.2088	.2453	.1937	.1336	.0519	-.0357	-.1302	-.2059	-.2722	-.3176	-.3523	-.3331	-.3147
-.2617	-.1844	-.1130	-.0126	.0567	.1262	.1030	.1998	.1992	.1708	.1067	.0627	-.0254	-.0704	-.1402
-.1676	-.1758	-.1849	-.1634	-.1406	-.0925	-.0437	.0057	.0504	.1062	.1569	.1954	.2343	.2332	.2354
.1095	.1318	.0690	-.0224	-.0963	-.1655	-.2117	-.2268	-.2105	-.1646	-.1171	-.0612	-.0054	.0150	.0372
.0359	.0374	.0225	.0011	-.0120	-.0403	-.0434	-.0266	-.0048	.0124	.0194	.0236	-.0089	-.0332	-.0669
-.1072	-.1222	-.1277	-.1255	-.1157	-.1053	-.0944	-.0839	-.0619	-.0309	.0073	.0539	.0922	.1453	.1767
.1990	.2185	.2309	.2213	.2037	.1901	.1656	.1329	.1040	.0793	.0590	.0456	.0081	-.0101	-.0239
-.0411	-.0467	-.0571	-.0466	-.0358	-.0281	-.0114	-.0088	-.0184	-.0205	-.0550	-.0819	-.1170	-.1574	-.1769
-.1734	-.1446	-.0993	-.0522	-.0032	.0440	.0809	.0989	.1198	.0960	.0562	.0105	-.0664	-.1412	-.1899
-.2298	-.2540	-.2492	-.2453	-.2004	-.1604	-.1261	-.0611	-.0161	.0312	.0666	.0922	.1029	.1037	.1030
.1005	.0955	.0963	.0949	.0949	.0971	.0671	.0348	-.0054	-.0432	-.0681	-.0870	-.0892	-.0708	-.0413
-.0200	.0252	.0476	.0900	.1286	.1586	.1784	.1772	.1418	.1035	.0153	-.0457	-.0977	-.1307	-.1288
-.1026	-.0539	.0090	.0742	.1300	.1756	.1868	.1911	.1804	.1418	.1046	.0803	.0311	.0076	-.0357
-.0642	-.0929	-.1197	-.1401	-.1373	-.1516	-.1126	-.0981	-.0473	-.0084	.0488	.0845	.1398	.1755	.1946
.2053	.1818	.1697	.1386	.1145	.0842	.0944	.0934	.0880	.1098	.1142	.1151	.1014	.0676	.0158
-.0523	-.1276	-.2125	-.3002	-.3570	-.4143	-.4187	-.4230	-.3705	-.3170	-.2190	-.1115	-.0027	.1307	.2122
.2739	.3094	.3155	.3127	.2840	.2211	.1577	.0712	-.0144	-.0938	-.1804	-.2538	-.3143	-.3606	-.3672
-.3794	-.3477	-.3147	-.2637	-.2030	-.1349	-.0566	.0177	.0781	.1275	.1777	.1821	.2003	.1978	.1709
.1675	.1580	.1522	.1517	.1278	.1170	.0915	.0844	.0740	.0825	.1007	.1326	.1641	.1863	.2228
.2089	.1685	.1446	.0928	.0252	-.0371	-.1129	-.1832	-.2462	-.3235	-.3663	-.4068	-.3897	-.3967	-.3443
-.3091	-.2501	-.1923	-.1271	-.0564	.0166	.0898	.1310	.1650	.1795	.2017	.2104	.2307	.2518	.2724
.2742	.2726	.2538	.2250	.1815	.1121	.0390	-.0465	-.1326	-.1889	-.2326	-.2345	-.2246	-.1932	-.1075
-.0214	.0700	.1450	.2165	.2338	.1984	.1390	.0375	-.0677	-.1570	-.2267	-.2910	-.3198	-.3340	-.3242
-.3114	-.2609	-.2144	-.1443	-.0660	.0173	.0976	.1560	.2001	.2158	.2084	.1867	.1544	.1214	.1049
.0871	.0702	.0079	.0957	.1267	.1475	.1949	.2220	.2389	.2452	.2380	.2045	.1685	.1250	.0843
.0313	-.0077	-.0540	-.0834	-.1220	-.1470	-.1768	-.1909	-.2028	-.2056	-.1929	-.1734	-.1455	-.1129	-.0709

-.0341	-.0072	.0255	.0332	.0460	.0475	.0352	.0280	.0169	.0079	-.0068	-.0167	-.0305	-.0380	-.0498
-.0535	-.0546	-.0500	-.0451	-.0329	-.0234	-.0080	.0026	.0139	.0211	.0238	.0212	.0201	.0155	.0112
.0078	.0057	.0035	.0047	.0052	.0063	.0092	.0095	.0109	.0103	.0080	.0058	.0033	.0013	.0003
.0003														

VERTICAL

MAXIMUM GROUND ACCELERATION = .250 G'S

MAXIMUM GROUND VELOCITY = 4.214 IN./SEC.

MAXIMUM GROUND DISPLACEMENT = .852 IN.

SIMULATED GROUND ACCELERATION

.0001	.0005	.0001	-.0001	-.0000	-.0012	-.0002	-.0056	-.0083	-.0070	-.0021	.0053	.0097	.0115	.0070
-.0064	-.0153	-.0217	-.0231	-.184	-.0107	.0021	.0077	.0202	.0245	.0244	.0162	-.0058	-.0206	-.0298
-.0293	-.0185	.0063	.0152	.0240	.0179	.0101	-.0019	-.0078	-.0043	.0014	-.0027	.0078	.0010	.0027
.0108	.0074	.0077	.0097	.0098	.0092	.0076	.0145	.0120	-.0010	-.0092	-.0120	-.0111	-.0006	-.0145
-.0167	-.0302	-.0227	-.0040	.0174	.0441	.0554	.0396	.0089	-.0303	-.0512	-.0537	-.0210	-.0072	.0014
.0355	.0454	.0773	.0992	.1173	.0939	.0519	.0406	.0273	.0661	.0800	.0481	-.0134	-.0490	-.0470
.0045	.0572	.1013	.0904	.0193	-.0566	-.0053	-.0905	-.0462	-.0047	.0225	-.0042	-.0614	-.0893	-.1070
-.0543	-.0055	.0388	.0444	-.3131	-.0803	-.1359	-.1265	-.0629	.0305	.1279	.1472	.1054	.0592	-.0263
-.0457	-.0465	-.0251	-.0108	-.0166	-.0244	-.0031	-.0421	-.0222	-.0006	-.0109	.0005	-.0141	-.0714	-.0907
-.1205	-.1018	-.0549	-.0183	.0115	-.0205	-.0336	-.0478	-.0328	-.0156	.0096	.0051	-.0416	-.0629	-.0940
-.0650	-.0390	-.0107	.0434	.0517	.0401	.0363	.0091	.0243	.0334	.0729	.0400	.0377	-.0434	-.1141
-.1190	-.0738	.0234	.1242	.1523	.1222	.0450	-.0159	-.0394	-.0450	-.0229	.0046	.0100	-.0036	.0016
.0109	.0343	.0745	.1129	.1089	.0742	.0323	-.0040	-.0160	.0130	.0636	.0059	.1007	.0917	.0663
.0238	-.0027	-.0334	-.0395	-.0278	-.0455	-.0303	-.0410	-.0696	-.0548	-.0360	.0073	.0522	.0632	.0353
-.0173	-.0152	-.0232	.0009	-.0201	-.0244	-.0723	-.0974	-.1267	-.0816	-.0410	.0209	.0336	.0597	.0373
.0121	-.0215	-.0532	-.0540	-.0697	-.0061	.0234	.0676	.0865	.0168	-.0509	-.0972	-.1044	-.0634	.0185
.0564	.0615	.0135	-.0418	-.0606	-.0477	-.0078	.0760	.0310	.0513	.0439	.0382	.0264	.0177	-.0151
-.0252	-.0205	.0133	.0620	.0768	.0607	.0331	-.0000	-.0381	-.0474	-.0446	-.0535	-.0450	-.0260	.0352
.1135	.1601	.1494	.0762	-.0009	-.0673	-.0439	.0092	.0800	.1277	.1099	.0593	.0077	-.0304	-.0366
-.0228	-.0005	-.0064	.0256	.0399	.0636	.0323	.0038	-.0233	-.0601	-.0800	-.0439	-.0477	-.0134	.0211
.0336	.0794	.0732	.0454	-.0143	-.0874	-.1289	-.1324	-.0897	-.0459	-.0060	.0103	.0140	.0009	-.0126
-.0305	-.0474	-.0747	-.0846	-.0869	-.0735	-.0591	-.0555	-.0280	-.0370	-.0670	-.0976	-.0058	-.1197	-.0914
-.0491	-.0117	.0093	.0049	-.0165	-.0263	-.0412	-.0401	-.0224	-.0257	.0202	.0438	.0635	.1075	.1333
.1287	.1159	.0749	.0317	.0202	.0136	.0216	.0467	.0567	.0689	.0677	.0913	.0795	.0696	.0397
.0101	-.0044	-.0161	-.0260	-.0299	-.0203	-.0229	.0029	.0366	.0360	.0096	-.0226	-.0654	-.0367	.0338
.1227	.2500	.1663	.0891	-.0101	-.0953	-.1162	-.0609	.0257	.0948	.1286	.0999	.0430	-.0251	-.0774
-.0881	-.0365	.0240	.0479	.0372	-.0133	-.0615	-.0851	-.0619	-.0262	.0036	-.0156	-.0672	-.1224	-.1494
-.1363	-.0944	-.0415	-.0242	-.0160	-.0099	-.0195	-.0104	-.0267	-.0405	-.0451	-.0786	-.0774	-.0546	-.0696
-.0636	-.0811	-.0506	.0008	.0673	.1149	.1550	.1145	.0636	-.0116	-.0543	-.0625	-.0161	.0045	.0364
.0462	.0418	.0293	.0369	.0578	.0844	.0849	.0552	.0072	-.0427	-.0481	.0195	.0770	.1500	.1872
.1696	.0070	-.0076	-.0918	-.1597	-.1526	-.1009	-.0206	.0411	.0774	.0710	.0495	.0162	.0209	.0321
.0325	.0276	.0053	-.0104	-.0071	-.0207	-.0228	-.0364	-.0442	-.0715	-.0461	-.0232	.0259	.0432	.0671
.0439	.0215	-.0009	-.0175	-.0097	-.0124	-.0219	-.0659	-.1006	-.1171	-.0703	-.0121	.0475	.0729	.0459
-.0065	-.0629	-.1198	-.1227	-.1159	-.0800	-.0630	-.0341	.0210	.0739	.1279	.1380	.1031	.0111	-.1022
-.1300	-.1067	-.0349	.0815	.1030	.0813	-.0040	-.0702	-.0859	-.0516	.0233	.0786	.0877	.0551	.0224
-.0466	-.0542	-.0374	.0044	.0415	.0690	.0571	.0313	.0116	-.0119	-.0080	.0017	.0207	.0372	.0458
.0329	.0339	.0319	-.0022	-.0106	-.0071	-.0169	.0008	.0341	.0686	.0588	.0270	-.0368	-.0631	-.1016
-.0941	-.0050	.0414	.0839	.0959	.0623	.0365	.0058	-.0024	.0232	.0149	-.0129	-.0591	-.1023	-.1006
-.0472	.0149	.0568	.0651	.0206	-.0233	-.0507	-.0752	-.0512	-.0499	-.0224	.0043	.0554	.0961	.1259
.1015	.0304	-.0415	-.0990	-.1148	-.0465	-.0239	.0444	.0363	.0321	-.0023	-.0028	.0019	.0118	.0252
.0154	-.0013	-.0047	-.0403	-.0333	-.0350	-.0405	-.0603	-.0501	-.0274	.0195	.0590	.0401	.0190	-.0497
-.0739	-.0624	-.0393	-.0273	-.0424	-.0504	-.0697	-.0274	.0159	.0568	.0343	-.0096	-.0868	-.0739	-.0484
.0307	.0599	.0724	.0247	-.0039	-.0020	.0112	.0374	.0516	.0259	.0304	.0257	.0790	.0679	.0730

.0296	.0201	.0077	.0164	.0310	.0430	.0311	-.0053	-.0014	.0214	.0543	.0429	.0464	.0079	-.0179
-.0265	-.0221	-.0045	-.0009	-.0109	-.0219	-.0039	.0030	-.0174	-.0104	-.0601	-.0799	-.0632	-.0136	.0161
.0174	-.0096	-.0533	-.1037	-.0004	-.0579	-.0250	.0202	.0179	.0285	.0217	-.0049	-.0277	-.0505	-.0929
-.0887	-.0562	-.0260	.0464	.0667	.0878	.0740	.0274	-.0139	-.0541	-.0839	-.1044	-.0922	-.0879	-.0250
.0299	.1001	.1126	.1160	.0947	.0526	.0519	.0647	.0939	.0961	.1140	.1116	.0997	.0971	.0504
.0167	-.0234	-.0662	-.0007	-.0623	-.0240	-.0131	.0152	.0245	.0069	-.0097	-.0339	-.0261	-.0256	-.0016
.0762	.1066	.1160	.0770	.0176	-.0595	-.0741	-.0688	-.0264	-.0013	.0245	.0351	.0241	.0335	.0319
.0413	.0196	.0075	.0005	-.0164	.0072	-.0007	-.0294	-.0247	-.0560	-.0520	-.0537	-.0612	-.0748	-.1026
-.1073	-.1090	-.0710	-.0139	.0200	.0399	.0626	.0564	.0387	.0046	-.0473	-.0059	-.1089	-.0892	-.0401
-.0083	.0162	.0097	-.0106	-.0035	.0182	.0631	.1123	.0809	.0447	-.0428	-.1370	-.1781	-.1761	-.1105
-.0401	-.0104	.0091	.0191	-.0060	.0034	-.0165	-.0209	-.0434	-.0466	-.0350	-.0285	.0051	.0029	-.0274
-.0421	-.0612	-.0402	-.0158	.0656	.0979	.1105	.1294	.1039	.0820	.0309	.0090	-.0005	-.0039	-.0018
.0416	.0754	.1035	.1314	.1262	.1048	.0478	-.0144	-.0745	-.1336	-.1414	-.1077	-.0509	.0001	.0006
.0863	.1138	.0635	.0334	-.0040	.0041	.0156	.0423	.0543	.0670	.0547	.0515	.0245	.0134	.0225
.0218	.0440	.0415	.0422	.0206	-.0025	-.0177	-.0035	.0034	.0048	.0012	-.0335	-.0090	.0060	.0643
.1071	.0808	.0054	-.0845	-.1581	-.1613	-.1076	-.0251	.0427	.0873	.0796	.0511	.0119	-.0419	-.0792
-.0923	-.0753	-.0636	-.0650	-.0692	-.0700	-.0966	-.0597	-.0051	.0294	.0160	-.0334	-.1101	-.1332	-.1344
-.0672	.0007	.0348	.0497	.0455	.0412	.0280	-.0049	-.0009	-.0095	-.0215	.0220	.0272	.0392	.0009
-.0232	-.0521	-.0419	-.0328	.0024	.0124	-.0078	-.0022	.0245	.0419	.0922	.1258	.0969	.0399	-.0495
-.0610	-.0637	.0127	.0885	.1057	.0813	.0201	-.0245	-.0089	.0240	.0503	.0525	.0312	-.0096	-.0024
.0272	.0929	.1425	.1230	.0719	-.0124	-.0469	-.0615	-.0304	-.0233	-.0023	-.0047	-.0111	.0269	.0460
.0574	.0221	-.0568	-.1384	-.1526	-.1108	-.0325	.0560	.0951	.1017	.0498	.0028	-.0741	-.1024	-.1108
-.0952	-.0607	.0136	.0535	.0743	.0390	-.0361	-.0761	-.0814	-.0986	-.0526	-.0355	-.0148	.0009	.0137
.0119	-.0135	-.0424	-.0790	-.0639	-.0516	.0288	.0727	.0833	.0939	.0752	.0595	.0215	-.0124	-.0761
-.0787	-.0669	.0100	.0540	.1126	.1031	.0551	.0042	-.0491	-.0536	-.0390	-.0023	.0406	.0346	.0268
-.0043	-.0253	-.0247	.0003	.0403	.0571	.0469	-.0118	-.0797	-.1280	-.1585	-.1506	-.1101	-.0718	-.0163
.0145	.0360	.0439	.0214	-.0195	-.0571	-.0782	-.0849	-.0526	.0128	.0497	.0622	.0374	.0059	-.0154
.0122	.0614	.1131	.1206	.0656	.0054	-.0632	-.0630	.0047	.0630	.1178	.1412	.1195	.0969	.0420
.0281	.0300	.0564	.0595	.0706	.0791	.0584	.0300	-.0041	-.0091	-.0099	-.0046	-.0206	-.0019	-.0240
-.0250	-.0087	-.0131	.0143	-.0039	-.0064	.0072	.0120	.0390	.0540	.0229	.0157	-.0552	-.0539	-.0934
-.0710	-.0397	-.0351	-.0130	-.0093	.0143	.0210	.0101	-.0189	-.0298	-.0307	-.0226	.0125	.0118	-.0356
.0182	.0185	.0383	.0193	-.0013	-.0600	-.1253	-.1599	-.1394	-.0674	-.0062	.0337	.0398	-.0174	-.0439
-.0527	-.0164	.0046	-.0056	-.0362	-.1054	-.1262	-.0881	-.0163	.0569	.1023	.1167	.0549	-.0020	-.0620
-.1008	-.0892	-.0314	.0387	.0932	.1042	.0727	.0162	-.0201	-.0216	.0049	.0425	.0541	.0749	.0650
.0620	.0808	.1079	.1039	.0704	.0526	.0199	-.0027	.0071	.0303	.0739	.1041	.0778	.0557	.0210
-.0281	-.0567	-.0767	-.0510	-.0207	-.0034	.0149	.0105	.0028	.0170	.0192	.0096	-.0404	-.1236	-.1707
-.1811	-.1236	-.0402	-.0192	-.0216	-.0634	-.0098	-.1033	-.0394	-.0028	.0176	.0216	-.0264	-.0703	-.0719
-.0662	-.0614	-.0479	-.0649	-.0424	-.0352	-.0359	.0090	.0234	.0413	.0499	.0533	.0377	.0044	-.0320
-.0608	-.0682	-.0347	.0196	.0706	.1262	.1010	.0521	-.0129	-.0631	-.0747	-.0608	-.0196	.0359	.0757
.0628	.0445	-.0294	-.0641	-.0579	-.0018	.0885	.1667	.1821	.1632	.0519	-.0227	-.0735	-.0934	-.0745
-.0430	-.0039	.0403	.0874	.1265	.1498	.1169	.0718	.0174	-.0479	-.0698	-.0363	-.0196	.0350	.0499
.0659	.0564	.0329	.0071	.0073	-.0208	.0215	.0150	.0391	.0252	.0260	.0006	.0249	.0595	.0751
.0960	.0667	.0549	.0223	.0004	-.0037	.0302	.0460	.0256	.0309	.0102	-.0011	-.0034	-.0009	.0001
-.0099	-.0266	-.0573	-.0915	-.0919	-.0863	-.0528	-.0800	-.0986	-.1303	-.1174	-.0806	-.0323	.0457	.0383
.0046	-.0308	-.0494	-.0234	.0027	-.0063	-.0130	-.0466	-.0647	-.0614	-.0709	-.0017	-.1009	-.1130	-.0092
-.1090	-.0830	-.0846	-.0832	-.0753	-.0505	-.0028	.0422	.0672	.0789	.0974	.0569	.0421	-.0076	-.0479
-.0431	-.0172	.0374	.1055	.1269	.1412	.1072	.0800	.0374	.0188	.0174	.0416	.0725	.0963	.1306
.1044	.0614	.0044	-.0256	-.0311	.0095	.0409	.0578	.0447	-.0273	-.0710	-.1133	-.0698	-.0564	-.0152
-.0343	-.0586	-.0053	-.1010	-.0539	.0029	.0692	.0645	.0236	-.0465	-.0737	-.0726	-.0199	.0359	.0640
.0376	.0019	-.0257	-.0150	.0106	.0361	.0407	.0099	-.0367	-.0502	-.0600	-.0432	-.0629	-.0023	-.1063
-.1043	-.0609	.0061	.1021	.1325	.0930	.0344	-.0602	-.1247	-.1300	-.0900	-.0536	.0017	.0337	.0402
.0212	.0092	-.0346	-.0539	-.0407	-.0109	.0539	.1067	.1436	.1379	.1029	.0631	.0329	.0262	.0536
.0681	.0677	.0643	.0374	.0373	.0300	.0726	.0928	.1002	.0972	.0056	.0515	.0321	.0177	.0144
-.0035	-.0010	-.0120	-.0045	-.0160	-.0172	-.0324	-.0340	-.0430	-.0514	-.0516	-.0557	-.0579	-.0536	-.0339

[illegible]	-.0009	-.0008	-.0091	-.0154	-.0277	-.0468	[illegible]	-.0380	-.0256	-.0223	-.0174	-.0232	-.0233	[illegible]
[illegible]	-.0235	-.0179	-.0195	-.0137	-.0159	-.0001	-.0461	.0002	.0041	.0050	.0014	.0026	-.0002	-.0014
.0000	.0033	.0046	.0074	.0059	.0037	.0045	.0040	.0071	.0062	.0065	.0043	.0017	.0001	-.0001
-.0000														

SECTION 5.5

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT I

IOWA ELECTRIC LIGHT & POWER COMPANY

PaR Job No. 3091

Design Calculations

MODULE STRESS ANALYSIS

PREPARED BY David L Pederson DATE 1-17-78

APPROVED BY R. Barry Whitaker DATE 1/19/78

REVISION NO. ______ DATE ______

ENVIRONMENTAL SERVICES, INC.
P.O. BOX 35244
MINNEAPOLIS, MINNESOTA 55435
(612) 854-8414

Serial No. ______

ENVIRONMENTAL SERVICES, INC.

DISTRIBUTION RECORD

SERIAL NO.	ORGANIZATION	DATE
R150-5.5	PaR Systems Corporation	

ENVIRONMENTAL SERVICES, INC.

REVISION RECORD

REVISION NO.	DESCRIPTION	APPROVED	DATE	CHECKED	DATE

5.5 MODULE STRESS ANALYSIS

5.5.1 Introduction

This section presents the detailed results of a seismic stress analysis of the high density Spent Fuel Storage Modules to be installed at the Duane Arnold Energy Center Unit I. The modules were examined for the stress levels in all the individual components and each component was compared with the safe allowable limits of stress for its material.

An 11x11 module and an 8x11 module were each idealized into finite element models for static stress analysis using SAPIV. The magnitude and direction of all of the loads were supplied by PaR from their time history analysis. This information was input to the SAPIV model to determine the element stress levels.

The SAPIV analysis shows that the stresses from all of the load cases studied are less than the allowable limits for the SSE condition.

5.5.2 Criteria and Assumptions

The analysis was based upon the criteria and assumptions discussed in this section.

5.5.2.1 Time History Analysis and Stress Analysis Interfaces

The nodal force results from the simple ANSYS model described in Section 5.4 were examined by PaR and ESI for equivalent static loads using the detailed SAPIV model discussed in this section. The force sets were applied to the detailed SAPIV model in approximately the same locations as on the ANSYS model so as to produce the same state of equilibrium.

The criteria for selecting the ANSYS time history force sets which could potentially cause maximum stresses in the module are listed below:

1) Maximum horizontal force at the top of the module
2) Maximum vertical force at middle of bottom casting
3) Maximum horizontal foot force
4) Maximum vertical foot force
5) Maximum bending moment
6) Maximum horizontal force in bottom casting (summation)

Each force set obtained from the ANSYS analysis occured during a rocking motion with lift-off. It was assumed that only two of the four foot pads of the module would be fixed to ground for the SAPIV analysis to maintain static equilibrium and prevent rigid body motion from occuring.

The time history analysis using ANSYS was based on a two dimensional planar model and only the vertical and one horizontal direction were examined. The ANSYS time history analysis provided loads for only 8x11 and 10x11 modules in the 8 and 10 cavity directions. To obtain loads for an 11x11 module in each horizontal direction, the 10x11 loads were simply increased by a factor of 11/10. To obtain loads for the 8x11 module in the 11 cavity direction, the 11x11 loads were factored by 8/11.

It is known that a wider module produces less rocking motion and therefore less force upon impact. The above factored loads are therefore more conservative than the actual loads.

The detailed SAPIV analysis was based on a three dimensional model. The boundary conditions were different in each direction because of the rocking motion of the module. This required separate SAPIV analyses in each horizontal direction. The two horizontal analyses at selected time steps were combined by the square root of the sum of the squares (SRSS) method.

The formula for this combination is given as

$$E' = \sqrt{(XZ)^2 + (YZ)^2}$$

where

E' = Safe Shutdown Earthquake (SSE) effect

XZ = X (horizontal) and Z (vertical) analysis (includes dead load)

YZ = Y (horizontal) and Z (vertical) analysis (includes dead load)

The modules are spaced together very closely in the spent fuel pool and close to the side walls. The forces of the water inside and around the modules are essentially transferred to the top and bottom castings through the cavities. Therefore, it was assumed that no lateral forces would be applied to the side plates.

5.5.3 Static Stress Analysis

5.5.3.1 Finite Element Model

The ANSYS stick model of an 11x11 and 8x11 module coupled with gap and slider elements is shown in Figure 5.5.3-1.

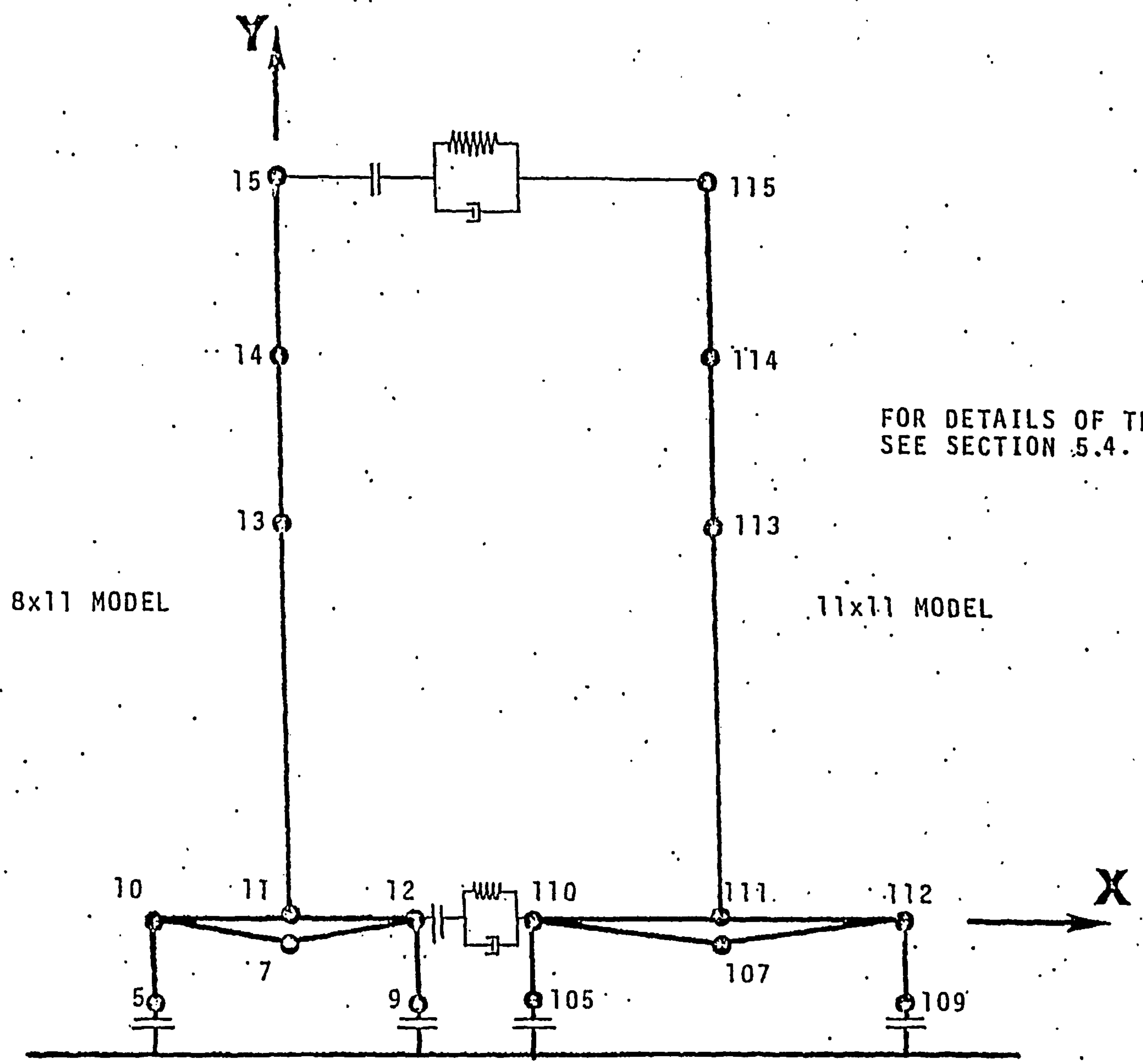
The 11x11 spent fuel module was idealized as a detailed finite element model of nodal points, flexural beam-column elements and plate elements as shown in Figure 5.5.3-2. Similarly, the 8x11 model was idealized as shown in Figure 5.5.3-3.

Two feet of the module were fixed to the ground, and the reactions on the other two feet from the time history analysis were applied directly as shown in Figures 5.5.3-4 and 5.5.3-5.

Material and section properties for 13 beam element types were determined. In all cases, the section properties were derived from the shapes of the top and bottom castings. A set of hand calculations in Appendix A.4 of this report shows each section in detail. Table 5.5.3-1 shows a summary of the beam element section properties used in the stress calculations.

5.5.3.2 The Computer Program

The computer program called SAPIV (public version) for static and dynamic analysis of linear structural systems was used to analyze the mathematical model. The development and documentation of SAPIV was sponsored by grants from the



FOR DETAILS OF THIS MODEL, SEE SECTION 5.4.

FIGURE 5.5.3-1
ANSYS TIME HISTORY MODEL

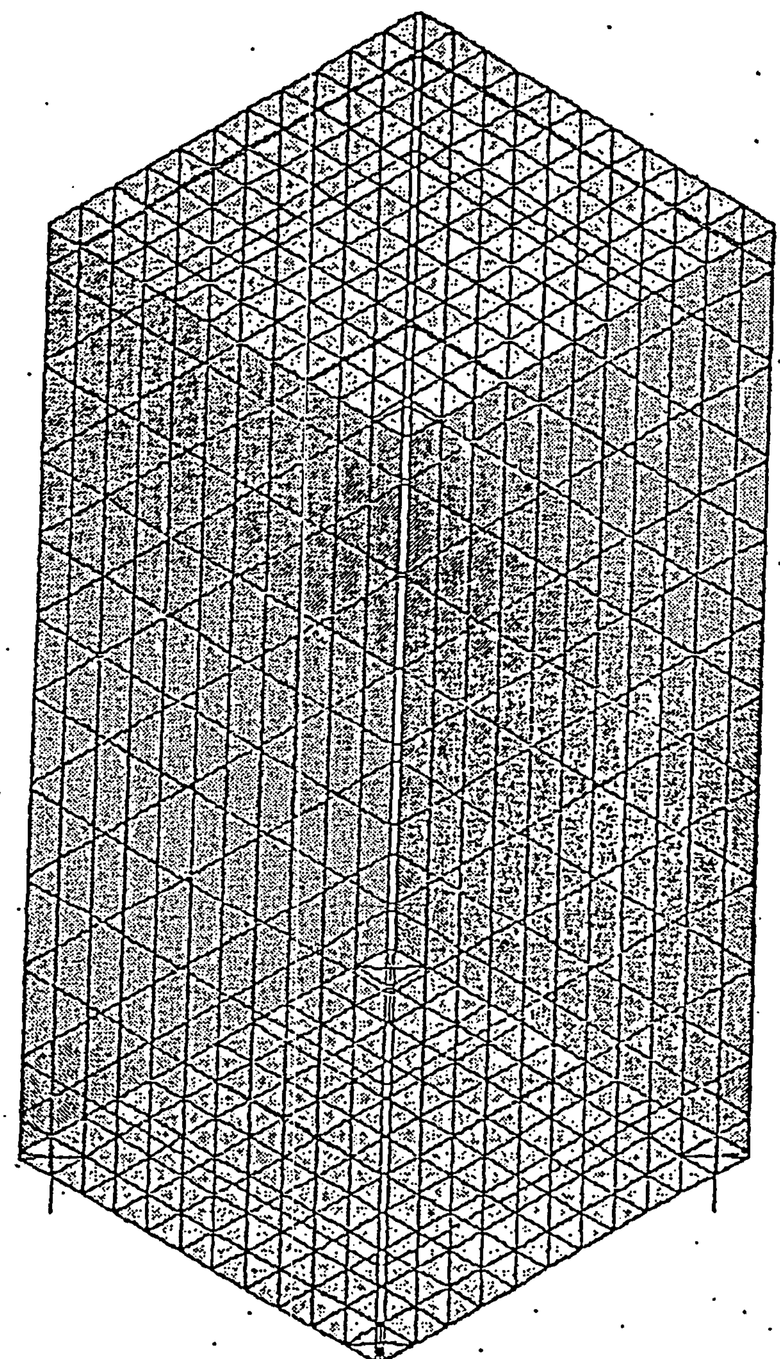


FIGURE 5.5.3-2
11x11 FINITE ELEMENT MODEL

PAR - 8 X 11 SPENT FUEL MODULE DUANE ARNOLD

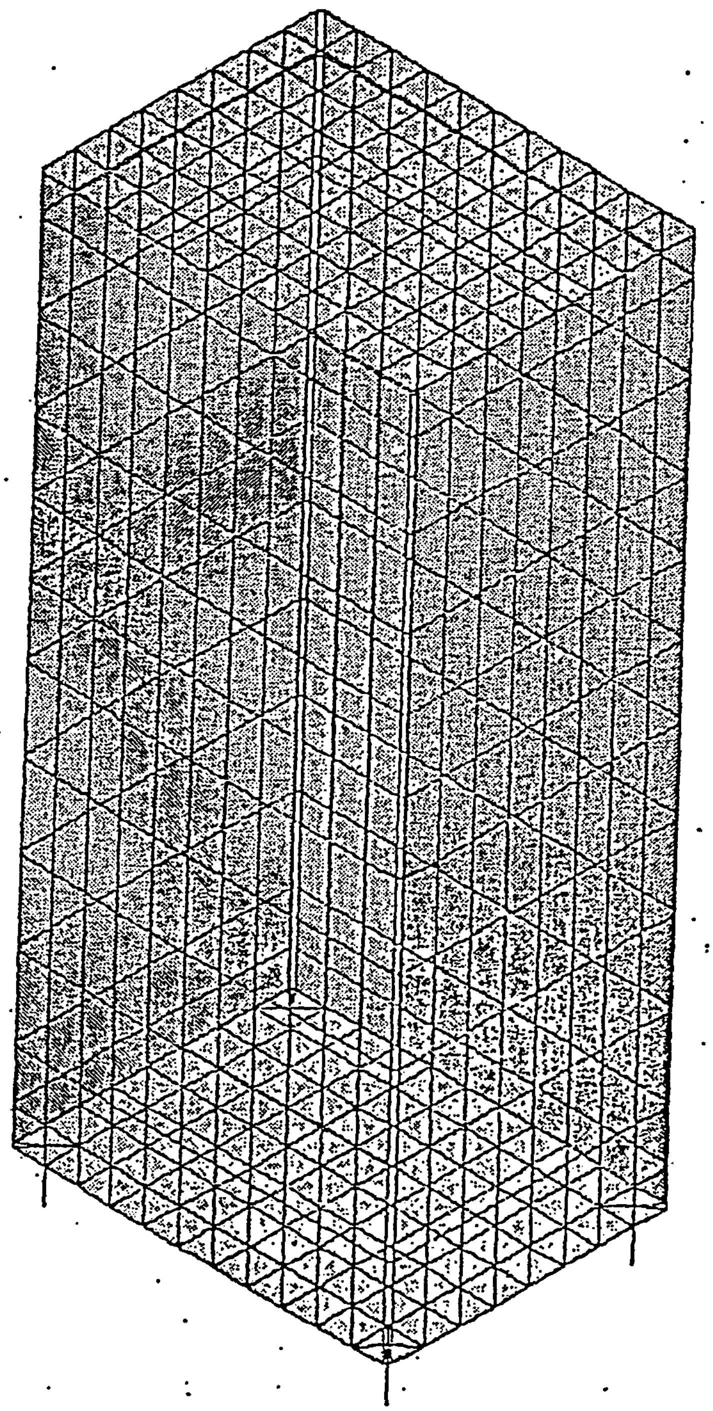


FIGURE 5.5.3-3
8x11 FINITE ELEMENT MODEL

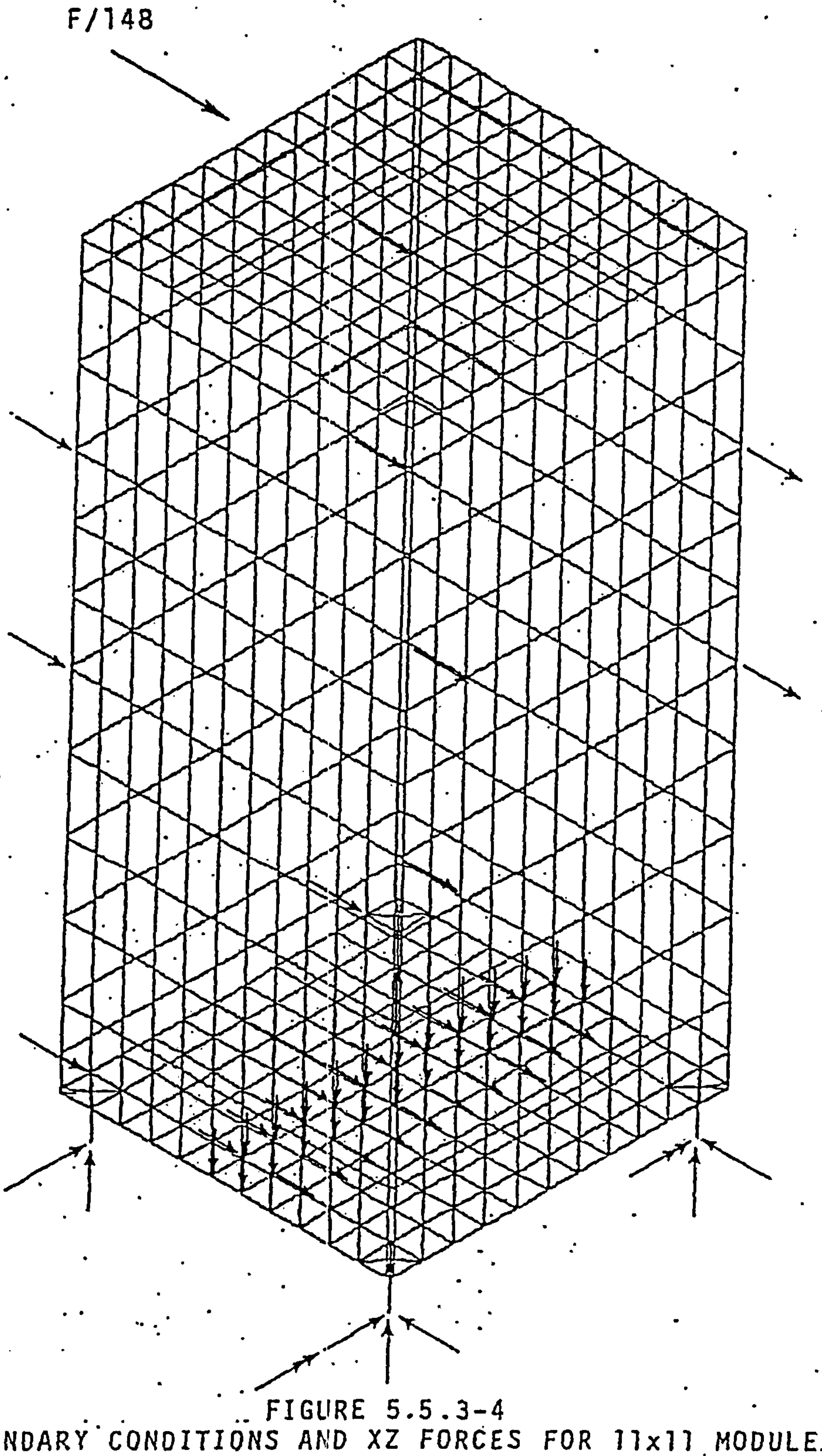


FIGURE 5.5.3-4
BOUNDARY CONDITIONS AND XZ FORCES FOR 11x11 MODULE.

PAR - 11 X 11 SPENT FUEL MODULE DUANE ARNOLD

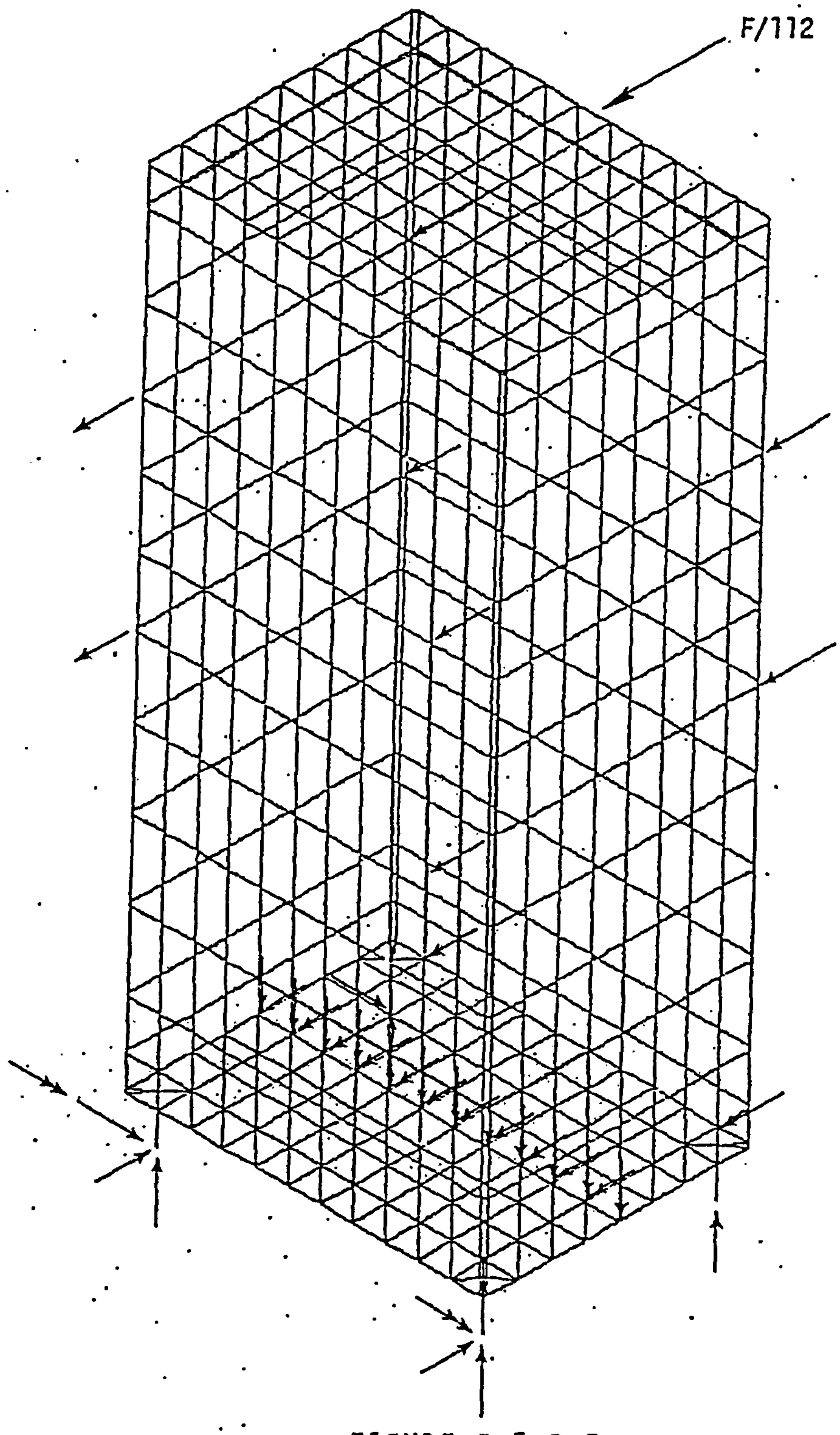


FIGURE 5.5.3-5
BOUNDARY CONDITIONS AND YZ FORCES FOR 8x11 MODULE

PAR - 8 X 11 SPENT FUEL MODULE DUANE ARNOLD

TABLE 5.5.3-1

SECTION PROPERTIES

SECTION	AREAS INCHES²			MOMENTS OF INERTIA INCHES⁴			SECTION MODULUS INCHES³		SLENDER-NESS	DESCRIPTION
	AX	AY	AZ	IX	IY	IZ	SY	SZ		
1	12.494	12.494	12.494	4.916	128.862	2.459	18.618	2.368	22.7	TOP CASTING - EXTERIOR
2	6.948	6.948	6.948	0.846	69.105	0.229	11.796	0.617	33.0	TOP CASTING - INTERIOR
3	10.220	2.180	8.853	3.558	70.469	5.450	13.841	2.862	27.7	BOT CASTING - EXTERIOR GUS
4	10.220	2.180	8.853	3.558	70.469	5.450	13.841	2.862	27.7	BOT CASTING - EXTERIOR GUS
5	7.604	2.180	6.237	2.991	22.651	4.860	6.259	2.739	42.1	BOT CASTING - EXTERIOR
6	10.857	3.609	8.123	4.265	64.316	9.920	18.851*	3.318	29.9	BOT CASTING - INTERIOR GUS
7	5.441	3.609	2.707	4.384	3.843	8.780	1.597	5.506	86.8	--NOT USED--
8	--	--	--	--	--	--	--	--	--	--NOT USED--
9	10.857	3.609	8.123	4.265	64.316	9.920	18.851*	3.318	29.9	BOT CASTING - INTERIOR GUS
10	8.625	3.609	5.891	4.364	20.647	9.520	5.991	5.581	47.3	BOT CASTING - INTERIOR
11	5.000	5.000	5.000	50.000	100.000	100.000	100.000	100.000	1.0	BOT CASTING - SPIDER/LEG
12	10.000	10.000	10.000	100.000	200.000	200.000	200.000	200.000	1.0	BOT CASTING - SPIDER/LEG
13	32.875	21.250	13.625	10.958	392.702	370.918	82.121	87.978	4.2	BOT CASTING - LEG

*Sections 6 and 9 have additional material at the bottom extreme fiber which was used for evaluating the section modulus and stress at the junction of the gusset and leg.

**Section 7 was used in the static analysis of the 8x11 only. The section was later modified to be the same as Section 5.

National Science Foundation and was authored by Klaus-Jurgan Bathe, Edward L. Wilson and Fred Peterson of the University of California, Berkeley, California. It is available as Report Number EERC 73-11 revised April, 1974, from the Earthquake Engineering Research Center at the University of California. SAPIV has been installed on a Control Data Corporation Cyber 74 computer in Minneapolis, Minnesota where the model was analyzed.

5.5.3.3 Dead Load Condition

The analysis used to obtain the vertical dead load was based on the same model as described above. The weight of the material was represented through the volume and density of materials in the model. The weight of fuel was applied to the node points of the lower gird. See Tables 5.7.3-2 and 5.7.3-6.

5.5.3.4 Seismic Load Conditions

Eight force sets were selected from the ANSYS time history analysis at different time steps using the criteria in Section 5.5.2-1. Two additional force sets were selected because they were close to the maximums outlined in the selection criteria. Table 5.5.3-2 shows the seismic loads which were input to the detailed 11x11 finite element SAPIV model and applied statically. Tables 5.5.3-3 and 5.5.3-4 show the 8x11 load sets.

TABLE 5.5.3-2
11x11 MODULE - FORCE SETS

FORCE SET	TIME (SEC)	HORIZONTAL FORCES (LBS)*							VERTICAL FORCES (LBS)*			
		105	109	110	111	113	114	115	105	107	109	111
1	1.334	30714	-122	55220	-52323	-27887	-667	-4938	105962	-80145	-12733	-13121
2	3.734	402	-9744	20406	-1409	-50502	-32597	73445	-41711	-22127	94100	-30282
3	4.610	-11	-50156	0	18853	13943	11163	6186	-15222	-89560	122254	-17514
4	7.290	-92	-54275	-41	14269	13863	-15397	10879	-35251	-72585	147532	-39740
5	7.294	330	-70307	-461	36500	16469	11966	5503	-26683	83118	124069	-14309
6	10.830	7696	-6947	2116	-15151	10973	4497	-3182	43098	-37005	74656	-80795
7	13.882	35531	-1310	-109	2833	-12397	-14411	-10138	136741	-75035	-26876	-34870
8	13.962	73747	-98	-64	-43249	-15188	-9958	-5191	119636	-79846	-18562	-21266

*For the location of the forces, see node points on Figure 5.5.3-1.

TABLE 5.5.3-3
8 x 11 MODULE - FORCE SETS (8 DIRECTION)

FORCE SET	TIME (SEC)	HORIZONTAL FORCES (LBS)*							VERTICAL FORCES (LBS)*			
		5	9	11	12	13	14	15	5	7	9	11
1	1.330	14188	-230	13639	-43074	32452	44713	-61689	71240	-32220	-19938	-19078
2	1.334	22483	5778	10391	-49547	47243	18302	-54649	100530	-32473	-35955	-32098
3	13.974	38282	144	-31221	-192	-6113	-1150	250	41978	-32780	-965	-8230
4	14.190	142	-28150	6600	-28	11152	7365	2919	-14133	-65963	98836	-18733
5	4.426	44854	-117	-30547	42	-7883	-4435	-1915	70550	-35426	-14816	-20303
6	13.882	19082	-635	4607	590	-6955	-9907	-6782	106800	-56529	-28512	-21748
7	13.962	-7647	-254	21184	308	7994	-2096	-19489	91981	-35440	-27401	-29135
8	14.186	509	4370	-23990	-40	-268	6195	13225	-17928	-65021	107640	-24679

*For the location of the forces, see node points on Figure 5.5.3-1.

TABLE 5.5.3-4
8x11 MODULE - FORCE SETS (11 DIRECTION)

FORCE SET	TIME (SEC)	HORIZONTAL FORCES (LBS)*							VERTICAL FORCES (LBS)*			
		5	9	11	12	13	14	15	5	7	9	11
1	1.330	26042	-271	-22379	34578	-29666	-27406	19102	86648	-55515	-13445	-17717
2	1.334	22338	-89	-38053	40160	-20282	-485	-3591	77063	-58287	-9260	-9542
3	13.974	25130	-25	-12589	-25	525	1456	-14473	70428	-46451	-11431	-12569
4	14.190	110	-16835	2637	-123	-3436	-1055	18702	-19513	-39402	76761	-17867
5	4.426	11983	2115	-6458	-119	-3210	-2706	-1605	45400	-41906	11309	-14824
6	13.882	25841	-953	2060	-79	-9016	-10481	-7373	99448	-54571	-19546	25360
7	13.962	53634	-71	-31454	-46	-11046	-7242	-3775	87008	-58070	-13500	-15466
8	14.186	117	-17833	851	-133	-942	1774	16167	-19360	-45244	81936	-17358

*For the location of the forces, see node points on Figure 5.5.3-1.

5.5.3.5 Distribution of ANSYS Forces on SAPIV Model

The ANSYS forces at points 15 and 115, Figure 5.5.3-1, were divided equally into the number of node points at the top of the modules as shown in Figures 5.5.3-4 and 5.5.3-5. The forces at points 13, 113, 14 and 114 were each divided into 4 nodal points on exterior corners of the SAPIV model. Forces at 12 and 110 were applied to the SAPIV nodes, in one cavity from the corners, at the level of the bottom casting. There were no forces at points 10 and 112. Vertical forces at points 11 and 111 were applied at the middle on the outside of the casting. Horizontal forces at points 11 and 111 were distributed as a line load normal to the seismic directions. Forces at 5, 9, 105 and 109 were each divided between two legs of the SAPIV model. The vertical force at the center, points 7 and 107, represents the inertia force of the fuel and grid and were distributed as a live load normal to the seismic directions. See Figures 5.5.3-4 and 5.5.3-5.

5.5.4 Discussion of Results

The detailed results of the spent fuel module stress analysis appear in the form of volumes of computer output entitled "11x11 (or) 8x11 Spent Fuel Module Analysis - Duane Arnold Energy Center Unit I" available through Environmental Services, Inv., P. O. Box 35244, Minneapolis, Minnesota 55435.

The contents of each volume is as follows:

Volume	Description
I	11x11 - Dead Load Analysis & Dropped Bundle Analysis
II	11x11 - Seismic X-Z Analysis
III	11x11 - Seismic Y-Z Analysis
IV	11x11 - Stress Analysis
V	8x11 - Seismic X-Z Analysis
VI	8x11 - Seismic Y-Z Analysis
VII	8x11 - Stress Analysis

5.5.4.1 Stress Evaluation

The normal limits (S) of stress for each section are listed in Tables 5.5.4-1 and 5.5.4-2 for beam and plate elements.

Stresses for beam elements were computed using the section properties given in Table 5.5.3-1. These stresses were combined using the interaction formulas for combined bending and axial stress. The acceptance criteria used for SSE stresses is given by the formula:

$$D+L+T_a+E' \leq 1.6(S)$$

The SSE cases which given the highest value of the interaction equation for each beam section type are listed in Tables 5.5.4-3 through 5.5.4-10 for the 11x11 module and Tables 5.5.4-11 through 5.5.4-18 for the 8x11 elements.

The stress levels for the side plate elements and corner angles are given in Tables 5.5.4-19 through 5.5.4-26 for the 11x11 module and Tables 5.5.4-27 through 5.5.4-34 for the 8x11 module. The same acceptance criteria was used for these elements.

Detailed information of the combined stresses are contained in Volumes IV and VII of the ESI computer output.

5.5.4.2 Shear Buckling Evaluation

The stress levels in the side plates were evaluated for shear buckling by combining the average horizontal shear and average vertical direct stress in the bottom rows of elements. The acceptance criteria used for the evaluation is given by the formula:

$$D+L+T_a+E' \leq 1.0(S)$$

The stresses were combined by the Aluminum Specification Design Rule 4.3 for combining axial shear and bending stresses in tube and web plate sections. The formula is given as

$$\frac{fa}{1.6Fa} + \frac{fb}{1.6Fb} + \left(\frac{fv}{1.6Fv}\right)^2 \leq 1.0$$

Since this was a finite element analysis, the out of plane bending of the side plates was included in the f_a terms in the computation of extreme fiber stresses. Therefore, the f_b and F_b terms were evaluated conservatively. The bottom two rows of elements on all four sides of the module were evaluated. The allowable shear stress, F_v, for both rows was based upon the Aluminum Specification Number 21 for stiffened flat plates. The side plates are stiffened because all four edges are supported continuously. The allowable stress, f_a, was based on Aluminum Specification Numbers 2, 14, 16 and 18. Since the bottom row is supported by bolts every 3.5 inches, the lowest maximum value was used for F_a. The allowable stress for the second row of elements up from the bottom was considered unsupported except at the corners so a minimum value was used for F_a.

The results of the shear buckling evaluation are given in Tables 5.5.4-35 through 5.5.4-50 for all eight force sets.

TABLE 5.5.4-1
NORMAL LIMITS OF STRESS

BEAM ELEMENT SECTIONS			
SECTION	NORMAL STRESS psi		
	F_a*	F_{by}*	F_{bz}*
1	6489	12600	12600
2	5159	12600	12600
3	7990	12600	9697
4	7990	12600	9697
5	7291	12600	9697
6	7886	12600	9697
7	5126	12600	9697
8**	--	--	--
9	7886	12600	9697
10	7039	12600	9697
11***	--	--	--
12***	--	--	--
13	8535	9700	12600

*The axial and bending stress allowables are based on the "Specifications for Aluminum Structures - Aluminum Construction Manual" published by the Aluminum Association, 420 Lexington Avenue, New York, New York 10017. The allowable stresses were computed from Specifications 7, 8, 11, 13, 15, 16 and 20 using a compressive yield, F_{cy} of 16000psi for the 356-T51 aluminum casting at 212°F.

**Section 8 was not used.

***Sections 11 and 12 were semi-rigid elements linking the leg section to the bottom casting. These sections were not evaluated for stresses.

TABLE 5.5.4-2
NORMAL LIMITS OF STRESS

SIDE PLATE AND CORNER ANGLE SECTIONS			
SECTION	NORMAL STRESS psi		
	TENSION	COMPRESSION	SHEAR
1*	19000	10850	2234
2*	19000	19000	2234
1**	19000	19000	12000
2**	19000	19000	12000
1***	18050	3789	2122

*Section 1 is the 0.5 inch thick side plate and Section 2 is the 0.25 inch thick corner angle. The allowable stresses are based on the "Specifications for Aluminum Structures - Aluminum Construction Manual" published by the Aluminum Association, 420 Lexington Avenue, New York, New York, 10017. The allowable stresses were computed from Specifications 1, 13, and 21.

**At the first row of elements at the top, bottom, or corners, the allowable stresses were permitted to go to their highest allowable value with a minimum slenderness limit.

***Normal limits at 212°F. used for shear buckling for the second row of elements up from the bottom.

TABLE 5.5.4-3
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 1 - TIME = 1.334 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	122	I	33.1	21.5	1106.3	.095
2	111	I	43.3	7.7	1243.3	.108
3	401	J	634.8	7564.7	2247.7	.898
4	402	I	1414.7	7113.0	4224.7	1.177
5	403	I	1292.7	2840.8	864.4	.492
6	280	J	1650.6	9801.8	2888.3	1.285
9	281	I	1792.2	9711.6	4636.8	1.476
10	462	I	238.0	15761.4	445.0	1.331
11	537	J	801.6	437.1	40.7	.121
12	540	J	1024.4	1551.5	210.1	.245
13	557	I	2284.0	4263.0	4030.2	1.027

TABLE 5.5.4-4
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 2 - TIME = 3.734 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	540.5	271.4	16644.8	1.426
2	12	I	669.6	81.1	18671.3	1.618
3	401	J	249.8	6065.0	909.1	.601
4	402	I	425.3	6078.3	1676.3	.708
5	524	I	485.7	2829.1	608.3	.354
6	379	J	493.6	3836.9	809.6	.451
9	380	I	450.3	3783.7	1548.3	.517
10	282	I	312.2	4317.4	402.0	.428
11	537	J	316.9	592.2	30.7	.082
12	539	J	596.8	742.4	30.1	.123
13	557	I	897.6	2765.8	2592.4	.596

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-5
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 3 - TIME = 4.610 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	51.8	49.1	1384.5	.122
2	12	I	54.2	14.7	1560.9	.136
3	390	J	247.5	6341.8	947.3	.626
4	391	I	330.3	6704.9	1877.0	.767
5	524	I	442.2	2969.2	226.3	.320
6	389	I	451.4	8322.6	913.4	.812
9	388	J	707.3	8239.6	1399.7	.888
10	471	J	89.5	18243.0	187.7	1.476
11	551	J	855.0	527.0	46.5	.134
12	552	J	747.9	1357.5	127.7	.195
13	560	I	2629.6	3053.8	2850.5	.849

TABLE 5.5.4-6
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 4 - TIME = 7.290 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	86.9	66.9	2439.3	.212
2	12	I	96.1	19.9	2747.7	.238
3	522	J	325.8	8059.8	624.3	.738
4	410	J	1397.6	7424.2	1145.2	.851
5	524	I	492.8	3464.7	153.4	.358
6	389	I	487.8	8771.9	1075.4	.869
9	388	J	732.4	8691.8	1258.6	.913
10	471	J	67.3	14918.4	150.1	1.206
11	551	J	943.3	606.4	51.2	.149
12	547	J	1161.7	978.8	111.1	.206
13	560	I	3173.3	3304.6	3084.6	.957

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-7
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 5 - TIME = 7.294 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	46.9	41.2	1229.2	.108
2	12	I	47.7	12.0	1387.5	.120
3	411	I	814.1	8645.3	117.4	.800
4	410	J	1837.0	8547.0	950.2	.966
5	409	J	1601.9	2857.8	680.5	.462
6	389	I	637.0	9711.8	1119.7	.967
9	388	J	1130.6	9620.5	2740.7	1.190
10	471	J	170.9	16834.4	346.8	1.389
11	551	J	1006.4	577.8	63.3	.155
12	552	J	1366.4	1548.6	179.4	.278
13	560	I	2668.6	4280.7	3995.7	1.071

TABLE 5.5.4-8
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 6 - TIME = 10.830 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	264	J	30.3	67.8	727.6	.066
2	111	I	32.0	16.0	815.0	.072
3	411	I	78.2	1775.1	324.4	.184
4	410	J	126.3	1686.2	1030.5	.253
5	406	I	851.9	3281.1	264.6	.405
6	389	I	115.2	2896.7	559.2	.302
9	388	J	243.6	2869.1	1327.4	.395
10	473	I	80.5	7095.4	130.5	.588
11	555	J	505.6	300.0	14.2	.077
12	552	J	326.2	486.4	17.0	.074
13	560	I	1605.8	422.9	394.8	.263

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-9
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 7 - TIME = 13.882 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	77.9	14.7	2266.7	.193
2	111	I	89.2	4.0	2557.4	.221
3	401	J	603.4	10222.0	318.8	.906
4	402	I	1129.5	9772.0	664.5	.985
5	524	I	883.1	3860.7	394.3	.468
6	280	J	285.2	11469.9	723.7	1.021
9	281	I	452.0	11369.1	597.6	1.021
10	462	I	13.8	14497.7	14.6	1.154
11	538	J	740.1	606.9	30.5	.127
12	540	J	527.7	1793.0	78.7	.203
13	557	I	2946.6	5445.4	5128.3	1.314

TABLE 5.5.4-10
11x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 8 - TIME = 13.962 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	1	I	47.4	44.1	1155.7	.103
2	12	I	45.4	13.1	1308.5	.114
3	401	J	941.5	12887.3	756.3	1.198
4	402	I	1844.7	12403.2	1989.5	1.420
5	524	I	1682.7	5462.8	472.3	.713
6	280	J	643.6	13302.1	998.9	1.240
9	281	I	1333.8	13184.7	3576.5	1.584
10	462	I	201.8	15276.9	380.0	1.280
11	538	J	876.3	1032.9	72.3	.178
12	540	J	1804.0	2054.4	179.2	.363
13	557	I	2579.2	7263.4	6825.5	1.593

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-11
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 1 - TIME = 1.330 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	197	I	571.7	207.4	11344.0	1.005
2	12	I	516.8	57.4	14730.5	1.274
3	288	J	451.5	4788.3	1859.7	.618
4	289	I	1092.3	4737.8	2901.2	.812
5	314	I	1441.7	6335.8	1881.4	.895
6	277	J	1028.9	5185.6	2501.8	.800
9	278	I	1194.6	5127.3	2353.2	.821
10	351	I	73.8	9041.6	141.3	.743
11	415	J	751.7	494.7	6.8	.117
12	411	J	1237.2	730.3	89.1	.193
13	419	I	1706.6	898.0	3398.0	.562

TABLE 5.5.4-12
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 2 - TIME = 1.334 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	197	I	490.2	180.7	9800.5	.868
2	12	I	449.9	44.8	12750.1	1.103
3	288	J	417.6	3994.5	2007.3	.567
4	289	I	1074.0	3934.2	3013.9	.757
5	307	J	420.9	9927.3	1393.6	.975
6	277	J	1166.8	4743.9	2764.4	.810
9	278	I	1340.9	4690.1	2406.7	.791
10	351	I	59.4	9486.5	257.7	.788
11	415	J	742.0	638.6	5.9	.128
12	411	J	1327.4	599.0	92.9	.192
13	419	I	1926.8	1399.0	2957.6	.605

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-13
8x11 MODULE -- BEAM STRESS SUMMARY

LOAD COMBINATION 3 - TIME = 13.974 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	199	I	103.5	25.3	1917.8	.170
2	180	I	102.1	7.5	2392.6	.210
3	200	J	320.9	4335.3	631.8	.442
4	201	I	599.2	4293.8	1270.9	.547
5	307	J	374.0	8446.1	458.6	.756
6	211	J	216.8	4933.1	462.1	.467
9	212	I	433.0	4878.9	2272.5	.676
10	351	I	160.7	8080.7	152.0	.680
11	399	J	435.4	299.4	34.0	.071
12	402	J	887.9	893.7	71.2	.168
13	419	I	1247.5	1819.0	2989.2	.571

TABLE 5.5.4-14
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 4 - TIME = 14.190 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	198	I	136.2	15.8	2528.9	.223
2	108	I	132.6	19.4	3168.9	.279
3	288	J	151.8	3843.7	339.1	.356
4	289	I	275.5	3948.8	455.1	.395
5	386	I	265.3	9548.9	325.3	.828
6	287	I	180.7	3738.3	607.3	.382
9	286	J	223.4	3686.2	628.6	.386
10	342	J	43.5	12705.6	45.3	1.018
11	415	J	799.8	717.8	65.2	.145
12	409	J	550.2	444.4	51.0	.096
13	421	I	1532.3	1798.2	1805.4	.508

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-15
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 5 - TIME = 4.426 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	199	I	20.1	15.5	397.6	.036
2	180	I	13.5	3.9	523.6	.044
3	299	J	411.7	4270.9	155.0	.397
4	300	I	854.3	4177.5	417.2	.481
5	307	J	375.5	10084.6	418.7	.882
6	211	J	205.2	3607.8	544.4	.369
9	212	I	166.4	3573.9	2288.6	.541
10	351	I	157.4	8025.0	128.4	.672
11	406	J	462.9	251.7	36.2	.071
12	402	J	868.8	814.5	70.8	.160
13	419	I	1276.1	2720.4	1350.5	.537

TABLE 5.5.4-16
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 6 - TIME = 13.882 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	198	I	79.1	16.4	1538.7	.136
2	180	I	57.6	7.1	2019.2	.172
3	200	J	376.8	5667.1	206.4	.510
4	289	I	702.1	5688.7	476.5	.588
5	307	J	222.6	10319.7	496.6	.893
6	211	J	164.4	6427.0	484.7	.581
9	212	I	321.9	6353.2	223.7	.568
10	351	I	22.4	12014.4	23.2	.959
11	399	J	635.4	332.9	19.7	.093
12	411	J	528.0	868.4	57.9	.128
13	419	I	2219.8	1129.9	3766.3	.675

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-17
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINATION 7 - TIME = 13.962 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	197	I	175.3	46.2	3507.3	.309
2	78	I	158.2	12.9	4567.6	.394
3	200	J	582.8	7314.8	272.3	.669
4	201	I	1214.9	7266.5	821.8	.813
5	307	J	419.4	8151.7	651.1	.757
6	211	J	374.6	7043.3	603.1	.669
9	212	I	994.1	6961.7	1788.3	.863
10	279	I	1011.5	7851.9	568.0	.825
11	400	J	609.8	523.4	47.7	.108
12	402	J	958.7	1143.0	93.3	.197
13	419	I	1926.1	488.8	4972.4	.671

TABLE 5.5.4-18
8x11 MODULE - BEAM STRESS SUMMARY

LOAD COMBINTATION 8 - TIME = 14.186 SECONDS						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	196	I	164.3	43.0	3150.5	.279
2	108	I	125.2	18.6	4145.2	.355
3	200	J	168.7	4105.1	220.0	.366
4	289	I	275.9	4181.3	852.2	.454
5	386	I	247.5	5626.5	517.9	.534
6	287	I	71.0	3319.4	304.8	.304
9	286	J	351.4	3264.6	1693.4	.478
10	343	I	129.9	13408.3	91.5	1.092
11	412	J	433.2	576.5	11.5	.091
12	414	J	591.3	672.9	35.9	.117
13	421	I	1663.5	679.8	1895.6	.415

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.5.4-19
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 1 - TIME = 1.334 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	123	7342.9	619.8	3671.5	0.386
2	36	2118.1	-41.3	1079.7	0.111

TABLE 5.5.4-20
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 2 - TIME = 3.734 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	386	8476.1	195.5	4335.8	0.446
2	36	7099.1	447.8	3325.7	0.374

TABLE 5.5.4-21
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 3 - TIME = 4.610 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	386	7055.6	1060.3	4057.9	0.371
2	36	6337.7	625.5	2856.1	0.334

TABLE 5.5.4-22
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 4 - TIME = 7.290 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	386	8321.1	963.7	4642.4	0.438
2	36	7233.1	614.9	3309.1	0.381

TABLE 5.5.4-23
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINTATION 5 - TIME = 7.294 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	385	8097.9	798.4	4049.0	0.426
2	36	5606.4	403.6	2601.4	0.295

TABLE 5.5.4-24
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 6 - TIME = 10.830 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	259	5987.0	1605.1	2993.5	0.315
2	24	4821.6	720.9	2050.4	0.254

TABLE 5.5.4-25
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 7 - TIME = 13.882 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	123	9397.2	1082.8	4698.6	0.495
2	48	3360.0	-418.4	1889.2	0.177

TABLE 5.5.4-26
11x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 8 - TIME = 13.962 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	123	10689.7	1580.9	5344.8	0.563
2.	48	6465.3	-87.8	3276.6	0.340

TABLE 5.5.4-27
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINTATION 1 - TIME - 1.330 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	447	5910.1	562.3	2955.1	0.311
2	15	4325.0	185.0	2070.0	0.228

TABLE 5.5.4-28
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 2 - TIME = 1.334 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	446	5908.4	907.7	2954.2	0.311
2	48	4175.2	349.0	1913.1	0.220

TABLE 5.5.4-29
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINTATION 3 - TIME = 13.974 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	447	4076.2	460.1	2038.1	0.215
2	24	1385.0	-4.4	694.7	0.073

TABLE 5.5.4-30
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 4 - TIME = 14.190 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	218	5353.0	-272.2	2812.6	0.282
2	24	5009.8	505.6	2252.1	0.264

TABLE 5.5.4-31
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 5 - TIME = 4.426 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	90	3946.5	547.3	1973.3	0.208
2	48	1939.0	154.5	892.3	0.102

TABLE 5.5.4-32
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 6 - TIME = 13.882 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	447	6007.1	570.8	3003.5	0.316
2	12	3628.3	482.2	1573.1	0.191

TABLE 5.5.4-33
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 7 - TIME = 13.962 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤1.6
		σ_{11}	σ_{22}	τ_{max}	
1	447	6843.8	1068.8	3421.9	0.360
2	12	5429.8	567.3	2431.3	0.286

TABLE 5.5.4-34
8x11 MODULE - PLATE STRESS SUMMARY
LOAD COMBINATION 8 - TIME = 14.186 SECONDS

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤ 1.6
		σ_{11}	σ_{22}	τ_{max}	
1	218	7278.9	166.2	3639.4	0.383
2	24	7112.8	944.0	3084.4	0.374

TABLE 5.5.4-35
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 1 - TIME = 1.334 SECONDS

SIDE	Average Stress on Side f_a	f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	2851	1280	0.241
B	2820	1002	0.135
C	2935	1188	0.274
D	2959	1288	0.246

TABLE 5.5.4-36
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 2 - TIME = 3.734 SECONDS

SIDE	Average Stress on Side f_a	f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	3319	876	0.182
B	3584	1012	0.213
C	3736	1096	0.234
D	3197	774	0.163

TABLE 5.5.4-37
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 3 - TIME = 4.610 SECONDS

SIDE	Average Stress on Side f_a	f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	4008	1401	0.309
B	3969	1501	0.333
C	4514	1617	0.383
D	3771	1328	0.284

TABLE 5.5.4-38
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 4 - TIME = 7.290 SECONDS

SIDE	Average Stress on Side f_a	f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	4451	1621	0.382
B	4508	1677	0.400
C	4814	1780	0.441
D	4206	1455	0.329

TABLE 5.5.4-39
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 5 - TIME = 7.294 SECONDS

SIDE	Average Stress on Side f_a	Average Stress on Side f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	3974	1563	0.350
B	4210	1656	0.384
C	4117	1648	0.378
D	3695	1469	0.315

TABLE 5.5.4-40
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 6 - TIME = 10.830 SECONDS

SIDE	Average Stress on Side f_a	Average Stress on Side f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	2846	1072	0.198
B	2919	1140	0.213
C	2992	1126	0.214
D	2787	1083	0.198

TABLE 5.5.4-41
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 7 - TIME = 13.882 SECONDS

SIDE	Average Stress on Side f_a	Average Stress on Side f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	3769	1568	0.344
B	3429	1309	0.268
C	3550	1452	0.306
D	3841	1561	0.344

TABLE 5.5.4-42
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 8 - TIME = 13.962 SECONDS

SIDE	Average Stress on Side f_a	Average Stress on Side f_v	$f_a/F_a+(f_v/F_v)^2 \leq 1.0$
A	3835	1694	0.381
B	3286	1361	0.363
C	3494	1534	0.325
D	3902	1698	0.385

TABLE 5.5.4-43
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 1 - TIME = 1.334 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	1990	890	0.397
B	1927	715	0.362
C	1972	773	0.377
D	1852	835	0.366

TABLE 5.5.4-44
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 2 - TIME = 3.734 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2270	972	0.456
B	2741	1065	0.551
C	2816	1125	0.574
D	2195	926	0.436

TABLE 5.5.4-45
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 3 - TIME = 4.610 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2200	1055	0.459
B	2579	1154	0.540
C	2752	1198	0.578
D	2240	994	0.455

TABLE 5.5.4-46
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 4 - TIME = 7.290 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2747	1274	0.594
B	3059	1335	0.659
C	3251	1407	0.708
D	2611	1188	0.553

TABLE 5.5.4-47
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 5 - TIME = 7.294 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2478	1203	0.534
B	2671	1202	0.566
C	2844	1288	0.613
D	2344	1057	0.484

TABLE 5.5.4-48
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 6 - TIME = 10.830 SECONDS

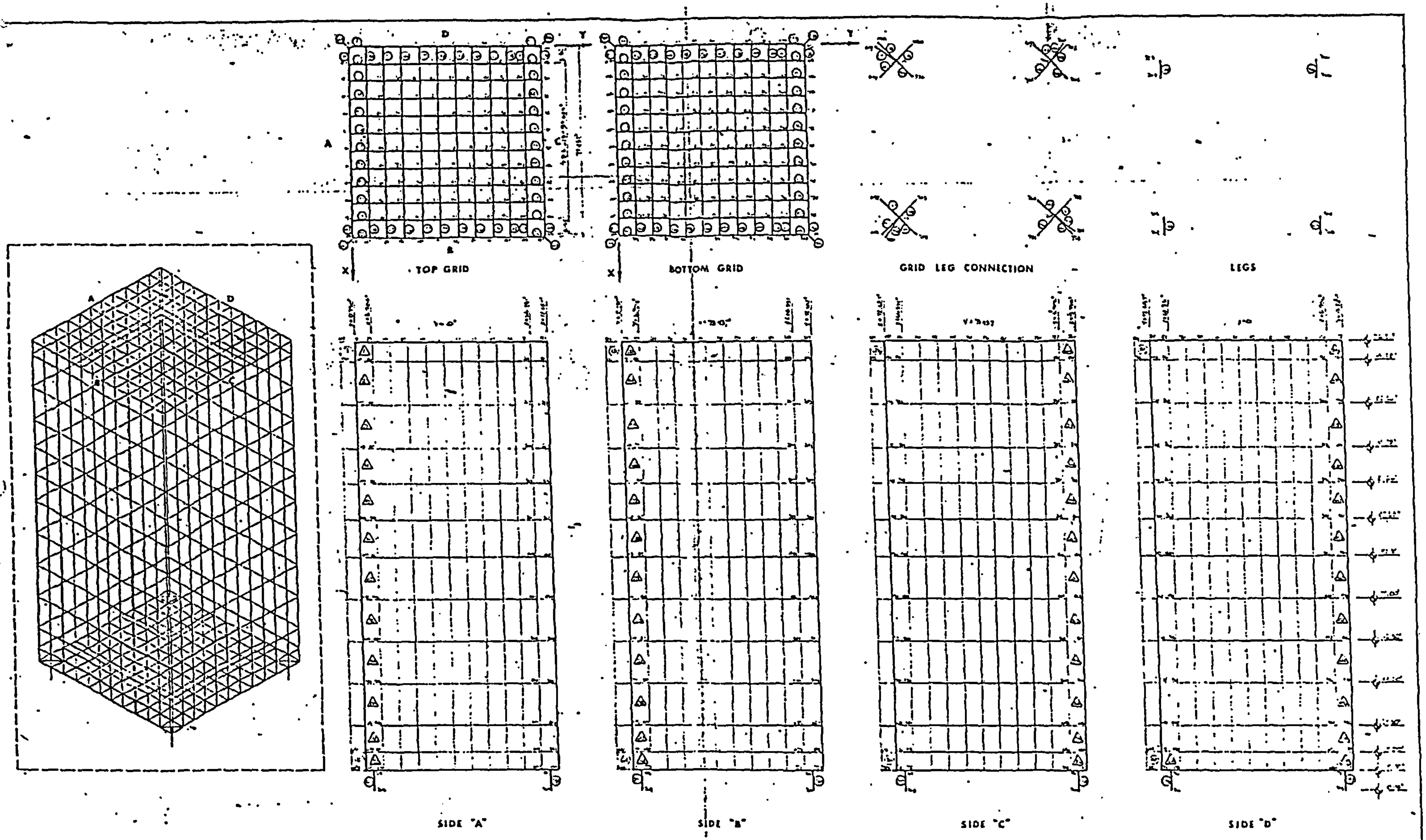
SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2017	959	0.412
B	2144	997	0.439
C	2244	991	0.455
D	1969	957	0.404

TABLE 5.5.4-49
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 7 - TIME = 13.882 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2605	1153	0.545
B	2175	846	0.421
C	2355	964	0.469
D	2435	1060	0.499

TABLE 5.5.4-50
11x11 MODULE - SHEAR BUCKLING EVALUATION
LOAD COMBINATION 8 - TIME = 13.962 SECONDS

SIDE	Average Stress on Side		$f_a/F_a+(f_v/F_v)^2\leq 1.0$
	f_a	f_v	
A	2273	1138	0.487
B	2109	870	0.414
C	2186	1016	0.450
D	1952	1059	0.419



5.5-40

PREPARED BY: David L. [illegible] DATE: 1-17-78

CHECKED BY: R. [illegible] DATE: 1/18/78

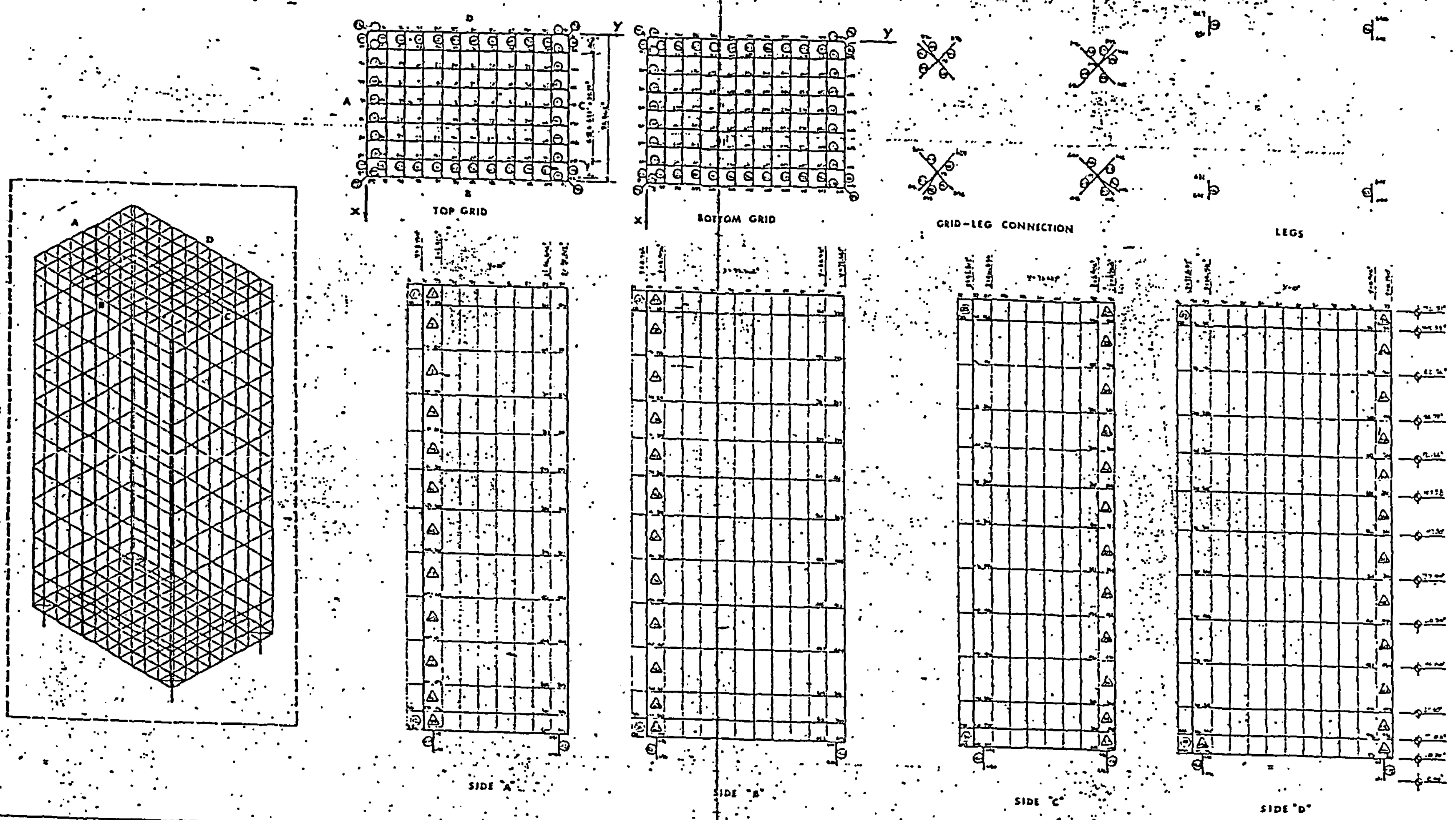
REVISION	DATE	DRAWN BY	CHECKED BY

CLIENT

PROGRAMMED & REMOTE SYSTEMS CORPORATION
3460 NORTH LEXINGTON AVENUE
ST. PAUL, MINNESOTA 55112

ESI

[illegible] SPENT FUEL MODULE
FINITE ELEMENT MODEL
FOR
DUANE ARNOLD & FITZPATRICK



PREPARED BY: David L. Anderson DATE: 1-17-78

CHECKED BY: R. Bury Wilson DATE: 1/1/78

REVISION	DATE	DRAWN BY	CHECKED BY

CLIENT

PROGRAMMED & REMOTE SYSTEMS CORPORATION
3460 NORTH LEXINGTON AVENUE
ST. PAUL, MINNESOTA 55112

ESI
ENVIRONMENTAL SERVICES INC.

8x13 SPENT FUEL MODULE
FINITE ELEMENT MODEL
FOR
DUANE ARNOLD & FITZPATRICK

JOB NO. 350
DATE 10-7-77
DWG. NO. 8155-7

5.5-41

PROGRAMMED AND REMOTE SYSTEMS CORPORATION
3460 LEXINGTON AVE. NO., ST. PAUL, MINNESOTA 55112
AREA CODE 612 484-7261 TELEX #29-7473

SECTION 5.6

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT NO. 1

Iowa Electric Light and Power Company
Cedar Rapids, Iowa

CONTRACT NO. 13764

Design Calculations

EQUIVALENT STATIC LOADS FOR FUEL IMPACT CONDITIONS

PaR Job: 3091

PREPARED BY [signature] DATE 12-6-78

CHECKED BY George V. Hoblish DATE 1-21-78

REVISION NO. ______ DATE ______

REVISION RECORD

REV. NO.	DATE	DESCRIPTION	CHECKED BY	APPV'D BY	DATE

FUEL DROP ANALYSIS

The following analysis determines the equivalent static load for the following drop conditions:

1) 18" fuel drop on the corner of the top grid castings.
2) 18" drop in the middle of the top castings.
3) A fuel drop full length through the cavity impacting on the bottom grid.

For the first two cases, the net impacting energy "E_{net}" was determined, which is:

(1) E_{net} = Potential Energy "E_p" - Absorbed Energy "E_a"

Where:

E_p = Wh

W = Buoyant weight of fuel bundle = 670#

h = drop height = 18"

"E_a" is the net energy absorbed by collapsing the tripod on the bottom fitting of the fuel bundle. A detailed analysis was performed using a computer program called "LAGS", Limit Analysis of General Structures, which is available thru the Structural Dynamics Research Corporation, 5729 Dragon Way, Cincinnati, Ohio. At a load of 4928#, all plastic hinges are fully developed and it will behave as a mechanism collapsing at this constant load. (See pages 5.2-6 thru 5.2-14). This load is less than the buckling and shearout load of the tripod members as shown on page 5.2-6 .

The total collapse height of the tripod is 1.48" conservatively assuming a 1.00" travel will sustain the collapse load of 4928#. The gross absorbed energy "E_a" will be:

$$E_a' = 4928\ (1.00) = 4928 \text{ in./lbs.}$$

The net absorbed energy "E_a" is the gross absorbed energy minus the potential energy of the fuel dropping thru the collapse distance.

$$E_a = 4928 - (670)\ (1.00) = 4258 \text{ in./lbs.}$$

Substituting values into equation 1 yields a net impact energy "E_{net}" of:

$$E_{net} = 670\ (18) - 4258 = 7802 \text{ in./lbs.}$$

This is the energy that must be absorbed by the module.

In order to set up a correct impact model it is important to know the module spring rate. Using the SAP IV finite element model (See Section 5.5) spring rates were determined by placing a 100 Kip load at the corner and middle of a 11 x 11 module at the top casting elevation. The respective deflections calculated were .0886" and .1297" yielding spring rates of:

$$100 \text{ Kip}/.0886" = 1163 \text{ Kip/in.} \quad \text{and}$$
$$100 \text{ Kip}/.1297" = 769 \text{ Kip/in.}$$

Consider impact energy losses due to interia resistance of the impacted mass;

See ROARK 5th Edition Page 580

Moving body of "M" strikes axially one end of bar mass "M_1" which has one end fixed, and a mass of "M_2" attached to the struck end of the bar.

$M = 745\#$. Fuel Bundle

$M_1 = 2356\#$ Four Side Panels $\quad M_1/M = 2356/745 = 3.16$

$M_2 = 1471\#$ Top Casting $\quad M_2/M = 1471/745 = 1.97$

$$K = \frac{1 + 1/3\ M_1/M + M_2/M}{(1 + 1/2\ M_1/M + M_2/M)^2} = \frac{1 + .33(3.16) + 1.97}{(1 + .5(3.16) + 1.97)^2} = .194$$

Consider resulting loads due to 18" drop in middle on 10x10. The equivalent static load "F" is given by

$$\text{"F"} = \sqrt{2\ (E_{net})\ K_s\ (K)}$$

Where: $E_{net} = 7.802$ Kip-in. (See Page 5.4- 4)

$K_s = 769$ Kip/in. (See Page 5.4- 4) $\sqrt{2(7.8)822(.194)} = 48.24$ Kips

$K = .194$

Consider Resulting Load for a Drop on the Corner of the Module

$$F = \sqrt{2\ E_{net}(K_s)\ K}$$

Where $E_{net} = 7.802$

$K_s = 1163$ $\quad F = \sqrt{7.8(2)\ 1121\ (.194)} = 59.3$ Kips

$K = .194$

These loads were put into the computer model and combined with dead loading to determine member stresses for these conditions (See Section 5.7.

In Section 6.1 of this report a drop test was performed to verify the relative magnitudes of these loads, and the structural integrity under actual conditions.

For the third impact case; a dropped fuel element all the way through the cavity, an ultimate load of 29.64 Kips was determined for the bottom casting support pocket. (See page 5.6-16).

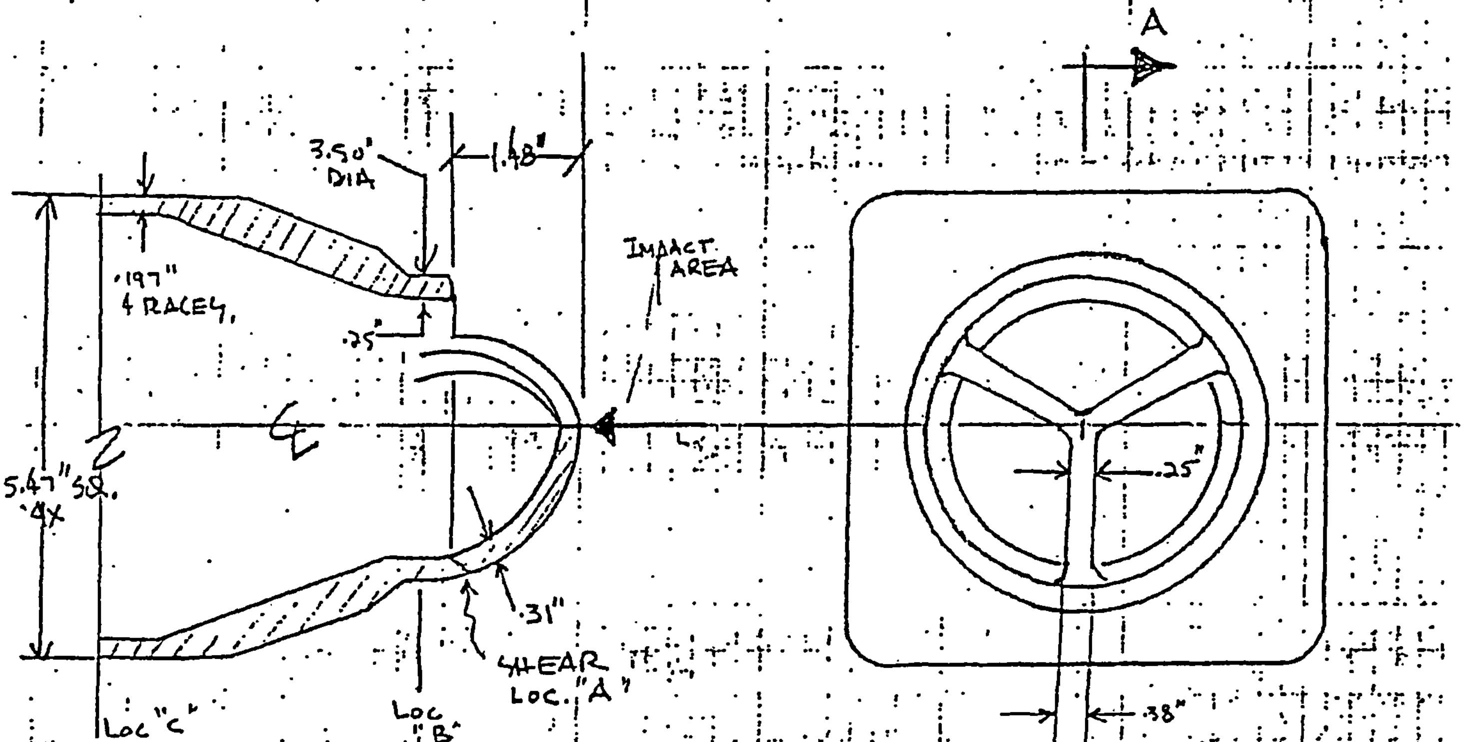
In Section 5.7 an analysis using the SAP IV model was done to determine the largest concentrated load plus dead load which could be applied to the middle of the biggest rack (11x11), and still maintain member stresses within the acceptable limits for this condition of 1.6 times normal allowable values. This load was calculated to be 47.34 kips, therefore , the resulting factor of safety is 47.34/29.64 = 1.59.

BY: [illegible] DATE 12/1/76 SUBJECT SHEET NO ... OF ...
CHKD. BY [illegible] DATE 3/10/77 JOB NO.

ENERGY ABOSORBING CAPABLITY OF: BWR BOTTOM FUEL FITTING

TOT. ULTIMATE LOAD ASSUMING A SHEAR FAILURE AT LOCATION 'A'

F_u = (3) .31 (.38) .577 (70,000) = 14273#



FUEL BUNDLE BOTTOM FITTING SECTION A-A

MATL - CF-8 SS
F_y = 28,000 psi @ 2% el.
F_u = 70,000 psi @ 40% el.

Kl/r OF TRIPOID MEMBER ($l \approx 2"$) = (.5)2"/.25(.289) = 14

* CRITICAL BUCKLING LOAD = .25(.31)(28/36)(20950) 1.9 = 2400#/member

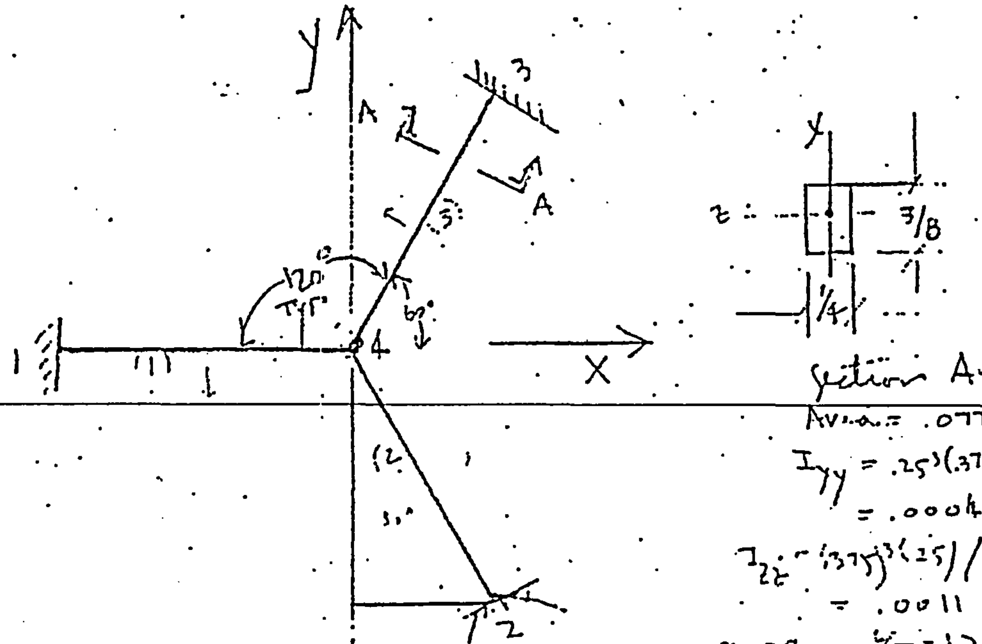
AVERAGE BUCKLING LOAD OF TRIPOID = (3) 148/200 (2400) = 5328#

YIELD AND ULTIMATE AT OTHER LOC.

LOC	AREA	YIELD LOAD	ULTIMATE LOAD
B	2.55 in²	71,471#	178,178#
C	4.15 in²	116,343#	290,858#

* See AISC MANUAL pg - 5-84 5.6-7

COLLAPSE MODEL BWR BOTTOM FUEL FITTING



Section A-A

Area = .0775 in²

$I_{yy} = .25^3(.375)/12$

$= .00048$

$I_{zz} = (.375)^3(.25)/12$

$= .0011$

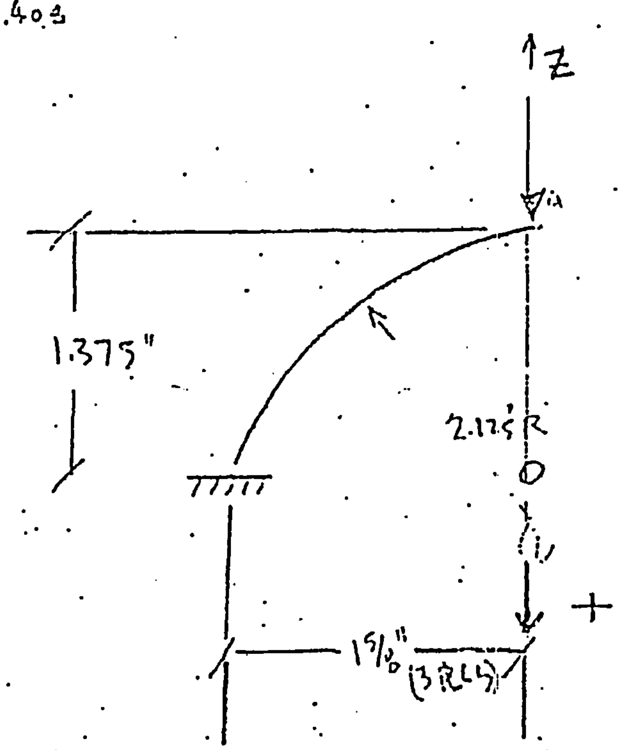
$a_y = a_z = 6/5 = 1.2$

$x = 1.625$ ...

$= .8125"$

$y = 1.625$ ...

$= 1.408$



Torsional constant

$K = ab^3\left[16/3 - 3.36\, b/a\left(1 - b^4/12a^4\right)\right]$

b .125

a = .16

$.125(.16)^3\left[16/3 - 3.36\, .125/.16\left(\;\right)\right]$

$\doteq .0014$

$Z_z = bh^2/4$

$= .375^2(.25)/4 = .0088$

$Z_y = .25^2(.31)/4 = .0048$

LIMIT ANALYSIS OF GENERAL STRUCTURES

STRUCTURAL DYNAMICS RESEARCH CORPORATION

COLLAPSE MODEL BWR BOTTOM FUEL FITTING

*** SPACE FRAME ANALYSIS ***

CURVED SPANS

SPAN	ANGLE	FORE END JOINT	AFT END JOINT	MAT. CODE	SECT. CODE	RADIUS	ROT. ANGLE	TEMP.
1	60.11	1	4	1	1	2.1	-90.0	
2	60.13	2	4	1	1	2.1	-90.0	
3	60.13	3	4	1	1	2.1	-90.0	

JOINT COORDINATES

JOINT	X	Y	Z
1	-1.625	.000	.000
2	.813	-1.408	.000
3	.813	1.408	.000
4	.000	.000	1.375

MATERIAL PROPERTIES

CODE	E	G	YIELD
1	29.0E+06	11.0E+06	45.0E+03

CROSS-SECTION PROPERTIES

CODE	AREA	MOMENTS OF INERTIA Z	MOMENTS OF INERTIA Y	SHEAR RATIO Y	SHEAR RATIO Z	TORSION CONSTANT	ECCENTRICITY Z	ECCENTRICITY Y
1	7.75E-02	1.10E-03	4.80E-04	1.20	1.20	1.40E-03		

PLASTIC SECTION MODULUS

CODE	Z(Z)	Z(Y)
1	8.800E-03	4.800E-03

SPECIFIED RESTRAINTS

JOINT	DIR	TYPE	VALUE
1		FIXED	
2		FIXED	
3		FIXED	

LOADING NO. 1:

APPLIED FORCES

JOINT	DIR	TYPE	VALUE

LIMIT ANALYSIS OF GENERAL STRUCTURES
COLLAPSE MODEL BWR BOTTOM FUEL FITTING

APPLIED FORCES

INT	DIR	TYPE	VALUE
4	Z	FORCE	1.50E+04

1.00

PLASTIC HINGE CRITERION COEFFICIENTS:

A1 = 1.000   B1 = 1.000   A2 = 1.000   B2 = 1.000

MAXIMUM ALLOWABLE Z DEFLECTION AT JOINT 4 = -1.250

PLASTIC HINGE TOLERANCE = 10. %

```
VERSION ...

ENTER DATA FILE NAME
? /COLL1

ENTER OUTPUT FILE NAME
? /COLLIOUT
IN BEAM
IN SETUP
IN DCPBD
DIAGONAL ELEMENTS: AVERAGE = 3.677E+05 SMALLEST = 5.806E+04 ROW   6

HINGE FORMS AT AFT  END OF SPAN   2 AT JOINT   4

SCALING FACTOR =  1.061150

TOTAL DEFLECTION =   -.004

ENERGY =   6.35E+00

IN SETUP
IN DCPBD
DIAGONAL ELEMENTS: AVERAGE = 3.110E+05 SMALLEST = 3.741E+04 ROW   6

HINGE FORMS AT AFT  END OF SPAN   1 AT JOINT   4

SCALING FACTOR =   .000543

TOTAL DEFLECTION =   -.004

ENERGY =   1.10E-02

IN SETUP
IN DCPBD
DIAGONAL ELEMENTS: AVERAGE = 2.619E+05 SMALLEST = 1.381E+04 ROW   5

HINGE FORMS AT FORE END OF SPAN   2 AT JOINT   2

HINGE FORMS AT FORE END OF SPAN   3 AT JOINT   3

HINGE FORMS AT FORE END OF SPAN   1 AT JOINT   1

SCALING FACTOR =   .581039

TOTAL DEFLECTION =   -.008

ENERGY =   1.80E+01

IN SETUP
IN DCPBD
DIAGONAL ELEMENTS: AVERAGE = 1.540E+05 SMALLEST = 7.153E+00 ROW   6
```

LIMIT ANALYSIS OF GENERAL STRUCTURES

STRUCTURAL DYNAMICS RESEARCH CORPORATION

COLLAPSE MODEL BWR BOTTOM FUEL FITTING

FINAL RESULTS:

JOINT DISPLACEMENTS

JOINT	X	Y	Z	THETA(X)	THETA(Y)	THETA(Z)
1	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
2	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
3	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
4	4.428E-06	-3.230E-07	-8.430E-03	5.239E-03	-3.015E-03	1.211E-06

JOINT REACTIONS

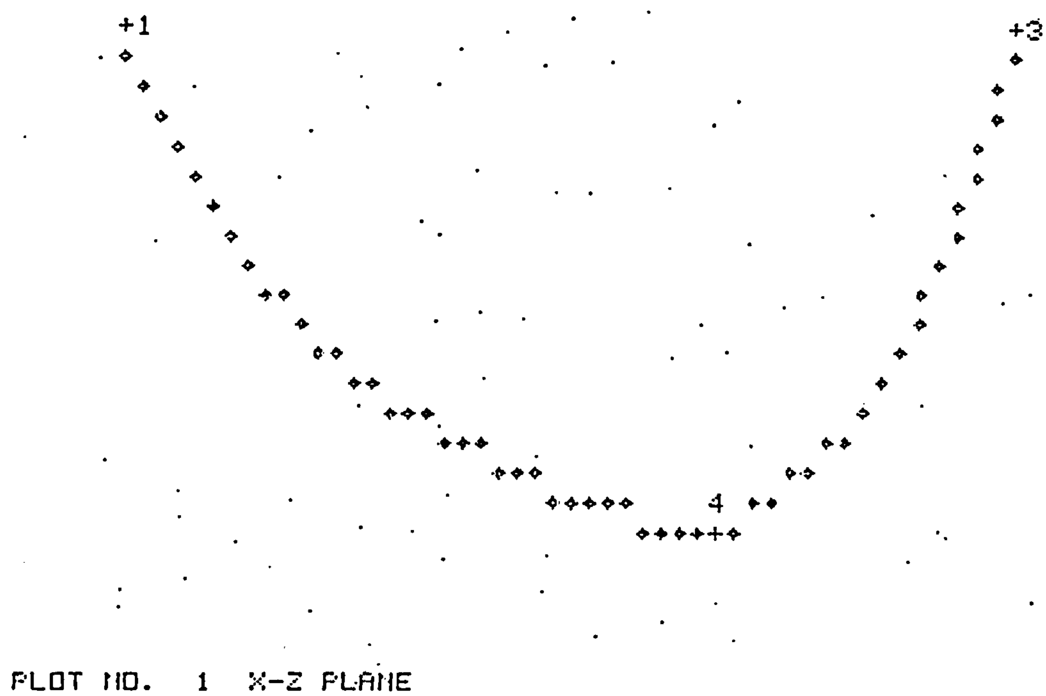
JOINT	F(X)	F(Y)	F(Z)	M(X)	M(Y)	M(Z)
1	1.941E+03	-4.285E-02	1.643E+03	-5.159E-03	3.956E+02	-3.322E-02
2	-9.707E+02	1.682E+03	1.643E+03	-3.431E+02	-1.980E+02	2.827E-02
3	-9.707E+02	-1.682E+03	1.643E+03	3.431E+02	-1.980E+02	4.937E-03

SPAN	JT.	FORCES X	FORCES Y	FORCES Z	MOMENTS X	MOMENTS Y	MOMENTS Z
1	1	2.201E+03	-1.274E+03	4.285E-02	-3.301E-02	-6.345E-03	-3.956E+02
1	4	-2.201E+03	-1.274E+03	-4.285E-02	5.663E-02	-4.716E-02	3.959E+02
2	2	2.201E+03	-1.274E+03	-2.725E-02	1.708E-02	3.613E-02	-3.962E+02
2	4	-2.201E+03	-1.274E+03	2.725E-02	-6.242E-03	1.741E-02	3.960E+02
3	3	2.201E+03	-1.274E+03	-1.557E-02	1.592E-02	-2.980E-02	-3.961E+02
3	4	-2.201E+03	-1.274E+03	1.557E-02	-5.037E-02	2.973E-02	3.961E+02

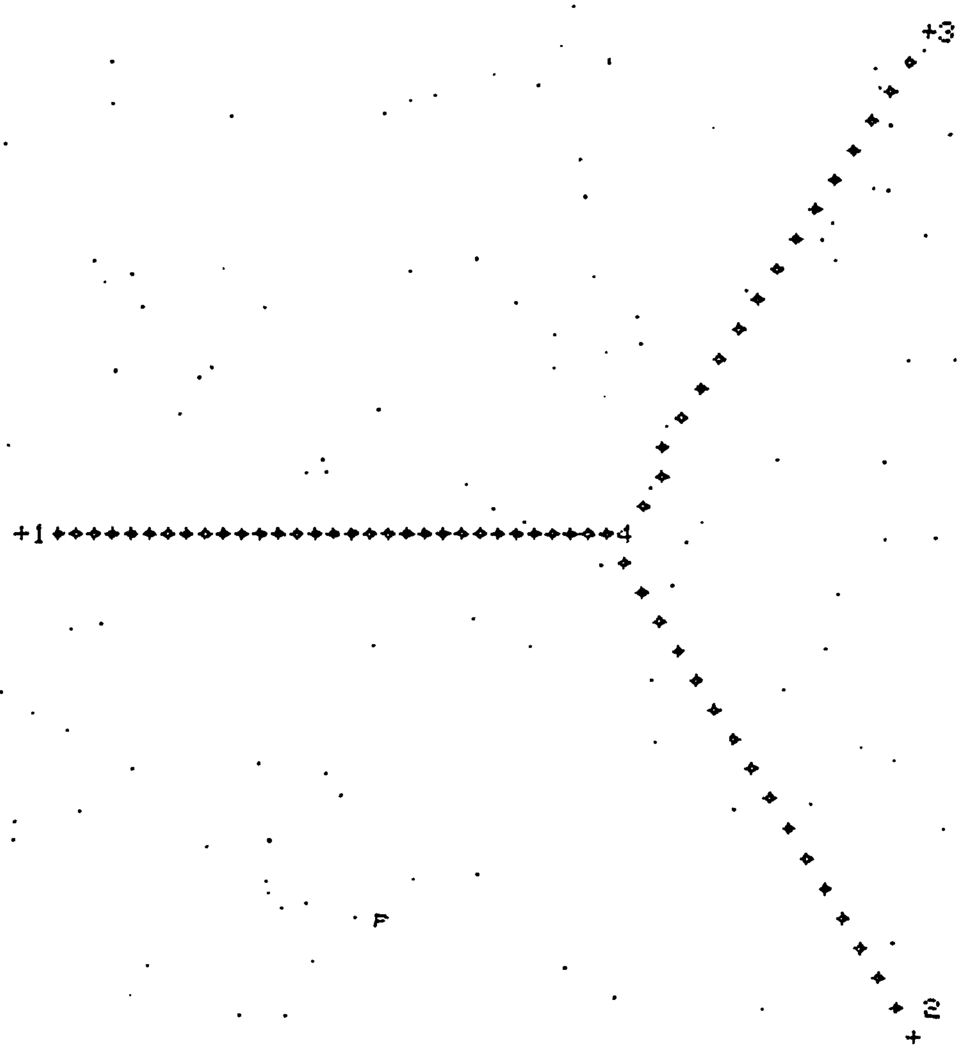
NET RESULTS AT END OF EACH PHASE

PHASE	ENERGY	DISPLACEMENT	F(X)	F(Y)	F(Z)
1	6.348E+00	-3.988E-03	.000E+00	.000E+00	-3.183E+03
2	6.359E+00	-3.992E-03	.000E+00	.000E+00	-3.185E+03
3	2.436E+01	-8.430E-03	.000E+00	.000E+00	-4.928E+03

TOTAL SCALING FACTOR = 1.642733



Undeformed Collapse Model
Figure 1



PLOT NO. 2 X-Y PLANE

Figure 2

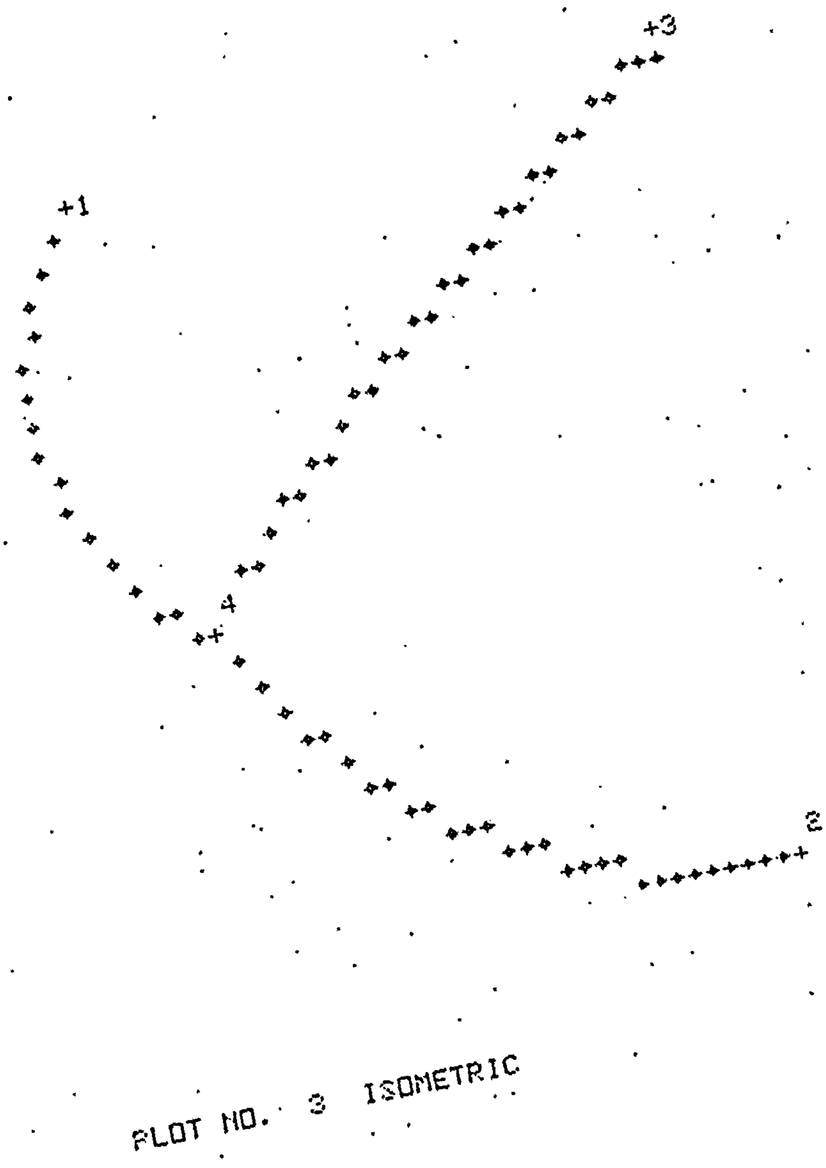
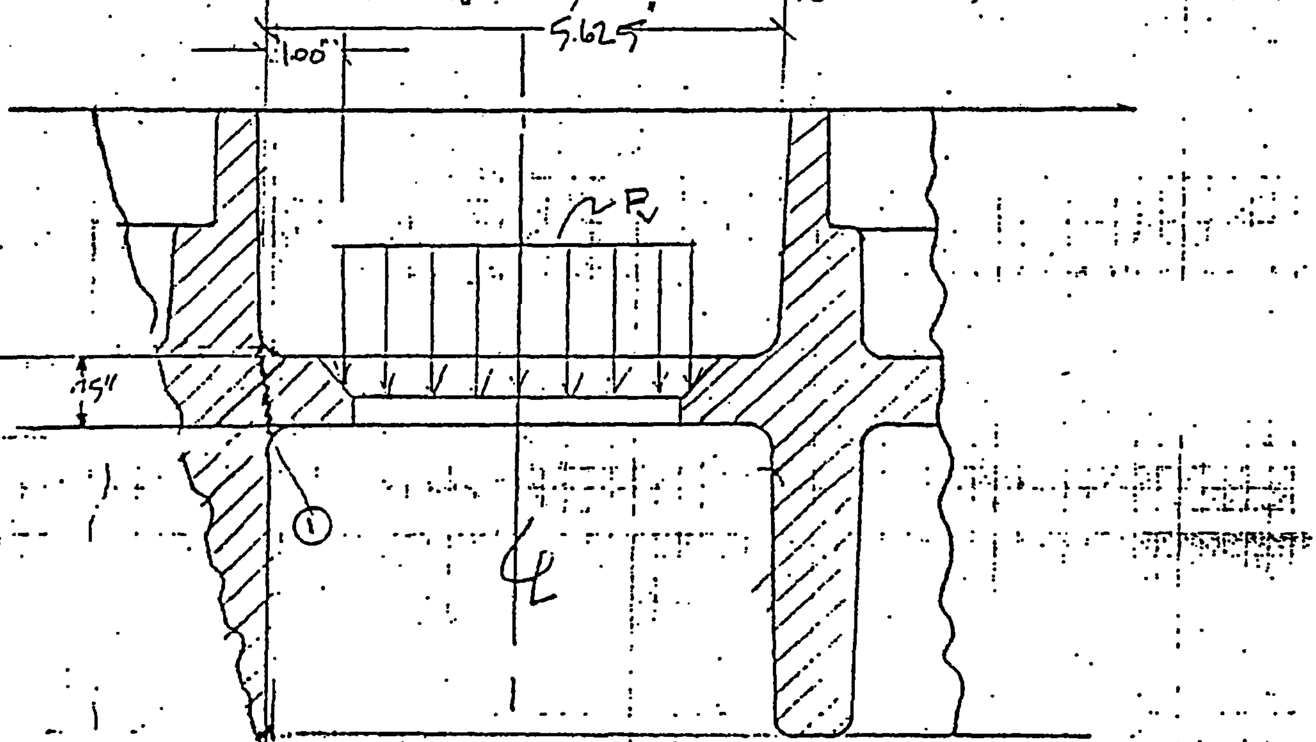


Figure 3

BY: ... DATE 12/1/77 SUBJECT ... SHEET NO ... OF ...
CHKD BY ... DATE 1/21/78 JOB NO. 3091

FUEL BUNDLE IMPACT ANALYSIS (BOTTOM GRID)

CONSIDER A FUEL DROP THRU A CAVITY AND IMPACTING ON THE BOTTOM GRID CASTING. DETERMINE THE ULTIMATE LOAD CAPACITY "P_v" . BOTTOM CASTING MAT'LS 356-T51 ALUM.
ULTIMATE STRENGTH = "F_u" = 23,000 psi @ 0.2% ELONGATION



SECTION MODULUS AT LOCATION ① WIDTH = 2(5.625) + 2(5.625 − .2) = 18.5 in
"b"

$S = bh^2/6 = (.75)^2(18.5)/6 = 1.73\ in^3$

AREA = .75 (18.5) = 13.18 in²

ULTIMATE STRESS FOR COMBINED BENDING & SHEAR IS GIVEN BY THE FOLLOWING EQUATION WHICH IS DEFINED IN THE AISC MANUAL SECTION 1.6.3 Pg. 5-23 & 5-134

(1) $f_t = F_t/F_v \sqrt{F_v^2 - f_v^2}$

$F_t = F_u = 23.0$ KSI

$F_v = F_{su} = .577(F_u) = 13.2$ KSI

$f_t = f_b = P_v l/S = P(1)/1.73 = .578 P_v$

$f_v = P_v/A = P_v/18.5 = .054 P_V$

SUB VALUES IN EQN 1

$.578 P_v = 23/13.2 \sqrt{(13.2)^2 - (.054 P_v)^2}$

$(.334)^2 P_v^2 = 174.2 - .003 P_v^2$

$P_v = 39.10$ KIPS

THE 11x11 BOTTOM GRID WAS ABLE TO WITHSTAND A CONC. LOAD OF 47.3 KIP BEFORE MEMBER STRESS INTERACTION REACHED 1.6 × NORMAL ALLOWABLE LIMITS WHEN COMBINED WITH DEAD LOADING SEE SECTION 5.7

SECTION 5.7

FUEL STORAGE SYSTEM DESIGN REPORT

DUANE ARNOLD ENERGY CENTER UNIT I

IOWA ELECTRIC LIGHT & POWER COMPANY

PaR Job No. 3091

Design Calculations

DROPPED FUEL BUNDLE ANALYSIS

PREPARED BY David L. Pederson DATE 1-17-78

APPROVED BY R. Barry Whitaker DATE 1/19/78

REVISION NO.________ DATE________

ENVIRONMENTAL SERVICES, INC.
P.O. BOX 35244
MINNEAPOLIS, MINNESOTA 55435
(612) 854-8414

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REVISION RECORD

REVISION NO.	DESCRIPTION	APPROVED	DATE	CHECKED	DATE

5.7 DROPPED FUEL BUNDLE ANALYSIS

5.7.1 Introduction

This section presents the results of dropped fuel bundle analysis of the 11x11 Spent Fuel Module for the Duane Arnold Energy Center Unit I. The analysis was examined for the following three drop conditions:

1) Fuel dropped in the middle from 18 inches above the top casting.

2) Fuel dropped on a corner from 18 inches above the top casting directly over a support foot.

3) Fuel dropped through a middle cavity the full length onto the bottom casting.

Equivalent static loads are computed and shown in Section 5.6 for each condition above. For each condition, the 10x10 module as described in Section 5.5 was analyzed for the dead and live load combined with the equivalent static load to determine stress levels in the components.

The analysis shows that the dropped fuel bundle analysis causes localized effects, and some of the components directly beneath the applied load show localized stress concentrations, but no overstress.

5.7.2 Criteria and Assumptions

The analysis was based upon the criteria and assumptions in this section.

5.7.2.1 Impact Conditions

For the first two conditions, the net impacting energy was determined to be the potential energy of the fuel bundle minus the energy absorbed by collapsing the bottom tripod fitting of the fuel bundle. The net impact energy was equated to the elastic strain energy and an equivalent static load was determined. The equivalent stiffness of the spent fuel module was determined by application of unit loads of 100 kips at the impact points to determine corresponding the deflections.

For the third condition, a fuel element was dropped all the way through the cavity to the bottom casting.

5.7.2.2 Static Analysis Condition

It was assumed that a static analysis of the module could be performed to simulate the impact conditions. Only two support feet of the module were assumed to be restrained to the floor in each horizontal direction. All four support feet were restrained vertically.

5.7.3 Static Stress Analysis

The same 11x11 finite element model as described in Section 5.5.3.1 of this design report was utilized for all dropped fuel bundle conditions. The SAPIV computer program was used to analyze the mathematical models.

The detailed results of the spent fuel module stress analysis appear in the form of a volume of computer output entitled "11x11 Spent Fuel Module Analysis - Duane Arnold Energy Center Unit I - Dead Load Analysis and Dropped Bundle Analysis - Volume I" available through Environmental Services, Inc., P. O. Box 35244, Minneapolis, Minnesota 55435.

5.7.3.2 Static Equivalent Loads

The locations of loads for the dropped fuel bundle analysis are shown in Figure 5.7.3-1 and are given in Table 5.7.3-1 for each of the three conditions as computed in Section 5.6.

TABLE 5.7.3-1

CONDITION	EQUIVALENT LOAD
1	48.24 KIPS
2	59.30 KIPS
3	47.36 KIPS

5.7.3.3 Maximum Stresses in Beam Elements

The stress levels in the beam elements of the module are shown in Tables 5.7.3-2 through 5.7.3-5 for dead and live load and for each condition above for dead and live loads plus impact. The ratio of the combined stresses to the normal allowable stresses is shown as an interaction value. The allowable stresses were permitted to reach 1.6 times the normal limits of stress for the dead and live loads plus impact.

5.7.3.4 Maximum Stresses in Side Plate Elements

The stresses in the 0.5 inch side plates and in the 0.25 inch corner angles are shown in Table 5.7.3-6 through 5.7.3-9 for dead and live load and for all three impact conditions. The ratios of combined stress to the normal allowable stress are shown.

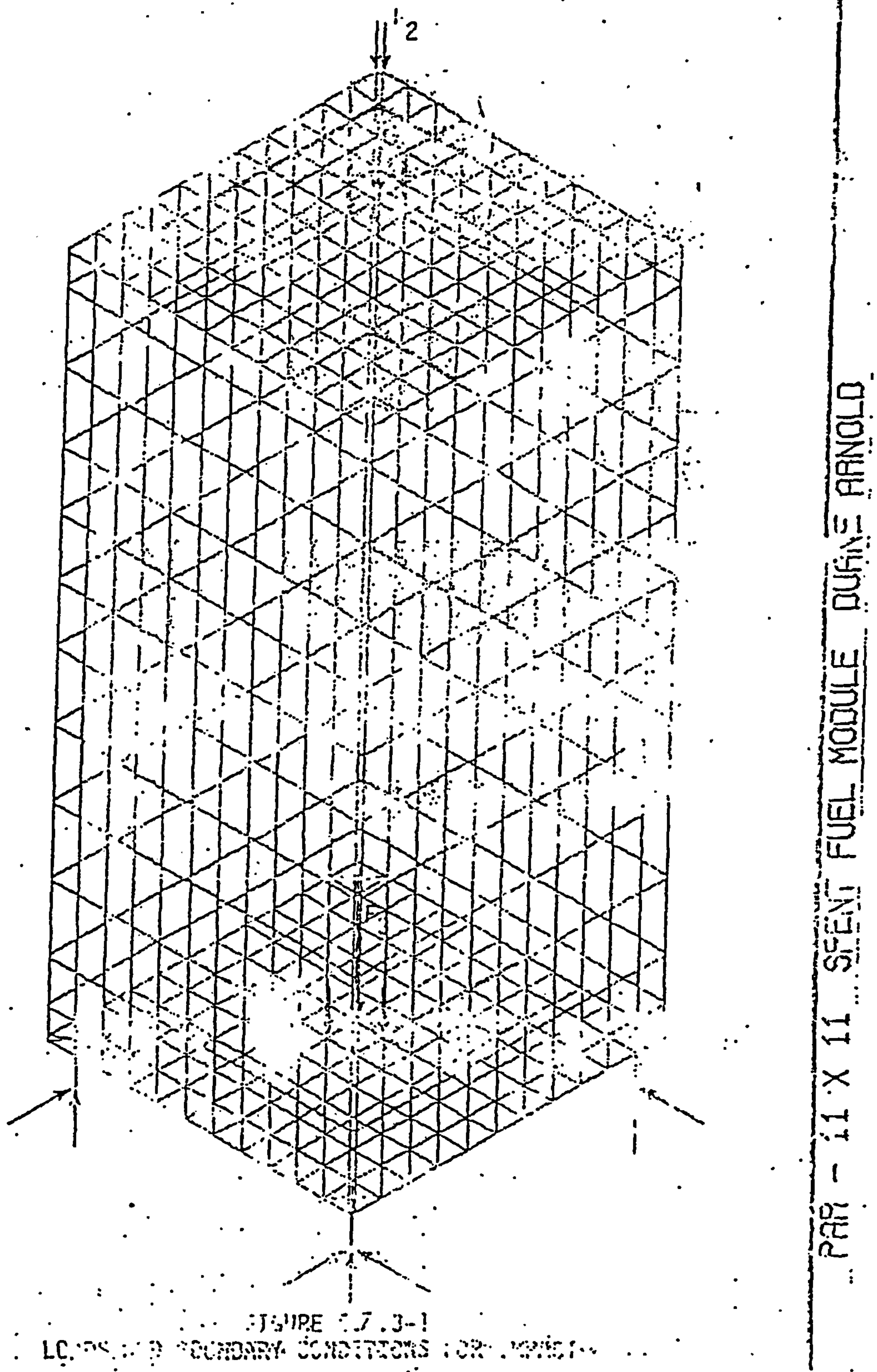

FIGURE 5.7.3-1
LOADS AND BOUNDARY CONDITIONS FOR ANALYSIS

TABLE 5.7.3-2
11x11 MODULE - BEAM STRESS SUMMARY

DEAD + LIVE LOAD						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	265	I	-.1	.4	16.0	.001
2	192	J	-.0	-47.2	5.2	.004
3	390	J	69.2	-753.6	67.4	.074
4	391	I	-104.5	916.4	-389.9	.124
5	409	J	219.2	-1047.8	104.6	.117
6	379	J	28.1	-2562.7	-143.2	.221
9	380	I	-142.0	2697.2	566.5	.287
10	462	I	-14.0	6309.6	.1	.502
11	543	J	189.1	-316.6	-2.7	.045
12	546	J	191.4	308.1	-1.5	.044
13	557	I	728.5	5.0	-4.6	.086

TABLE 5.7.3-3
11x11 MODULE - BEAM STRESS SUMMARY

DEAD + LIVE + DROPPED BUNDLE AT MIDDLE OF TOP CASTING - CONDITION 1						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	265	I	2.5	1.0	866.9	.069
2	194	I	.6	7968.8	6.3	.633
3	390	J	80.4	-474.1	94.3	.056
4	391	I	-125.6	624.7	-546.2	.119
5	409	J	298.0	-1171.8	149.9	.139
6	379	J	39.8	-3149.3	-191.4	.274
9	380	I	-195.8	3272.5	785.5	.361
10	462	I	-19.7	6176.3	-.5	.492
11	543	J	252.3	-361.7	-3.6	.055
12	546	J	262.2	360.2	-2.0	.056
13	557	I	1095.8	5.6	-5.2	.129

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.7.3-4.
11x11 MODULE - BEAM STRESS SUMMARY

DEAD + LIVE + DROPPED BUNDLE AT CORNER OF TOP CASTING - CONDITION 2						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤ 1.6
	ELEMENT	END	fa	fby	fbz	
1	1	J	395.8	-3213.7	-409.8	.328
2	13	J	119.9	-823.2	-1286.8	.180
3	401	J	99.6	1215.1	-103.5	.117
4	278	J	156.7	762.0	655.2	.144
5	409	J	445.7	-1392.4	464.6	.204
6	280	J	78.8	-4291.3	-200.2	.369
9	281	I	-277.4	4253.3	-424.7	.410
10	461	J	21.8	-6218.5	165.6	.513
11	538	J	349.8	504.6	-5.0	.077
12	540	J	340.5	-527.0	-2.4	.077
13	557	I	2223.9	1.7	-1.5	.261

TABLE 5.7.3-5
11x11 MODULE - BEAM STRESS SUMMARY

DEAD+LIVE+DROPPED BUNDLE THROUGH MIDDLE OF BOTTOM CASTING-CONDITION 3						
SECTION	MAXIMUM AT		COMBINED STRESS psi			INT.* ≤1.6
	ELEMENT	END	fa	fby	fbz	
1	265	I	-.2	.8	23.1	.002
2	193	I	.0	48.8	9.8	.005
3	390	J	136.3	-1903.5	109.4	.176
4	391	I	-202.6	2262.2	-629.5	.265
5	409	J	367.5	-1987.8	163.0	.212
6	379	J	44.8	-5012.1	-244.0	.428
9	380	I	-233.1	5306.2	924.5	.540
10	462	I	-22.3	20025.0	1.0	1.592
11	543	J	322.7	-606.5	-4.7	.082
12	546	J	317.2	580.6	-2.5	.079
13	557	I	1087.6	9.9	-9.3	.129

*Note: INT. is defined as the ratio of computed stress to allowable stress.

TABLE 5.7.3-6
11x11 MODULE - PLATE STRESS SUMMARY FOR D+L LOAD

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. $\leq$1.6
		σ_{11}	σ_{22}	τ_{max}	
1	132	48.9	-2374.6	1211.7	0.219
2	24	-558.1	-3160.1	-1301.0	0.166

TABLE 5.7.3-7
11x11 MODULE - PLATE STRESS SUMMARY FOR CONDITION 1

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. $\leq$1.6
		σ_{11}	σ_{22}	τ_{max}	
1	132	-160.8	-3240.4	1620.2	0.299
2	24	-695.4	-4074.2	-1689.4	0.214

TABLE 5.7.3-8
11x11 MODULE - PLATE STRESS SUMMARY FOR CONDITION 2

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. ALLOW. $\leq$1.6
		σ_{11}	σ_{22}	τ_{max}	
1	397	-620.0	-7878.0	3939.0	0.726
2	37	-1975.3	-10423.0	-4223.9	0.549

TABLE 5.7.3-9
11x11 MODULE - PLATE STRESS SUMMARY FOR CONDITION 3

SECTION	MAX AT ELEM	PRINCIPAL STRESS psi			PRINC. / ALLOW. ≤ 1.6
		σ_{11}	σ_{22}	τ_{max}	
1.	132	316.5	-4133.2	2224.9	0.381
2	24	-1009.6	-5617.3	2303.9	0.296