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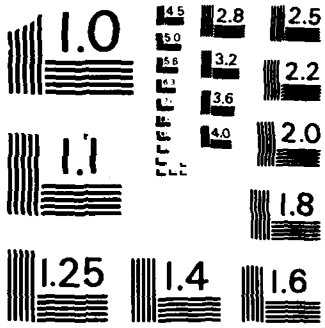


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STRUCTURAL ANALYSIS
OF THE
SOUTH MOORING DOLPHIN
U. S. NAVCOMSTA
H. E. HOLT
EXMOUTH AUSTRALIA

FPO-1-85 (5)
MAY 1985

# Ocean Engineering


CHESAPEAKE DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON NAVY YARD
WASHINGTON, DC 20374


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# STRUCTURAL ANALYSIS OF THE SOUTH MOORING DOLPHIN U. S. NAVCOMSTA H. E. HOLT EXMOUTH AUSTRALIA

FPO-1-85 (5)
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CHESNAVFACENGCOM performed a structural analysis on the south mooring dolphin at the Naval Communications Station, H.E. Holt in Northwest Australia in the aftermath of a 3 December 1982 collision with the structure by a commercial shipping vessel, MV "SARGODHA" and subsequent above water repairs (Con't)

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performed by the facility. Diver inspection before and after the repairs uncovered significant remaining underwater damage to the jacket joints on the lowest two levels. This analysis compares the structural integrity of the as-built structure to that of the structure in its current state. The main-frame computer program SACS III owned by EDI Inc. and made available by contract for government use by Control Data Corporation was the primary analytical tool used.

The structure's original design, although not consistent with the modern standards and codes, is adequate for the structure's intended use in sustained winds of 35 knots and with the associated 14 feet seas. The dolphin was designed to be on the verge of yielding in a typical hurricane environment with sustained 100 knot winds and the 26 feet maximum storm waves likely at the site.

The structure has been repaired adequately for continued use as a mooring dolphin for its intended purpose. Diver inspections should be conducted on a semi-annual basis beginning as soon as feasible. Mooring use should be immediately curtailed it the site experiences storm winds of 65 knots or greater or if waves approximately 20 feet high are observed overtopping the deck. In the event of a major storm or observations of new structural damage, CHESNAVFACENGCOM should be tasked to update this structural assessment before any resumption of use.

Although the north dolphin, the breasting dolphins and the main pier are in excellent condition with may years of remaining useful life, the south dolphin should be considered as only temporary. No economical method is known for repairing the damaged underwater portions to the original strength. Additionally the full effect of the cracks detected can only be guessed, but it is sure to worsen with time. For this reason we recommend immediate initiation of procedures for a MILCON removal and replacement of the dolphin.

STRUCTURAL ANALYSIS OF THE

SOUTH MOORING DOLPHIN

U. S. NAVY COMMUNICATIONS STATION

H. E. HOLT, EXMOUTH AUSTRALIA

REPRODUCED AT GOVERNMENT EXPENSE

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## ONE. EXECUTIVE SUMMARY

CHESNAVFACENGCOM performed a structural analysis on the south mooring dolphin at the Naval Communications Station, H. E. Holt in Northwest Australia in the aftermath of a 3 December 1982 collision with the structure by a commercial shipping vessel, MV "SARGODHA" and subsequent above water repairs performed by the facility. Diver inspection before and after the repairs uncovered significant remaining underwater damage to the jacket joints on the lowest two levels. This analysis compares the structural integrity of the as-built structure to that of the structure in its current state. The main-frame computer program SACS III owned by EDI Inc. and made available by contract for government use by Control Data Corporation was the primary analytical tool used.

The structure's original design, although not consistent with the modern standards and codes, is adequate for the structure's intended use in sustained winds of 35 knots and with the associated 14 feet seas. The dolphin was designed to be on the verge of yielding in a typical hurricane environment with sustained 100 knot winds and the 26 feet maximum storm waves likely at the site.

The structure has been repaired adequately for continued use as a mooring dolphin in up to 50 knot winds. If the site experiences a major storm, further damage to the structure is expected, possibly resulting in a total collapse of the dolphin.

In the near-term, we recommend continued use of the mooring dolphin for its intended purpose. Diver inspections should be conducted on a semi-annual basis beginning as soon as feasible. Mooring use should be immediately curtailed if the site experiences storm winds of 65 knots or greater or if waves approximately 20 feet high are observed overtopping the deck. In the event of a major storm or observations of new structural damage, CHESNAVFACENGCOM should be tasked to update this structural assessment before any resumption of use.

Although the north dolphin, the breasting dolphins and the main pier are in excellent condition with many years of remaining useful life, the south dolphin should be considered as only temporary. No economical method is known for repairing the damaged underwater portions to their original strength. Additionally the full effect of the cracks detected can only be guessed, but it is sure to worsen with time. For this reason we recommend immediate initiation of procedures for a MILCON removal and replacement of the dolphin.

## TWO. BACKGROUND

CHESNAVFACENGCOM was requested by NAVFACENGCOM on 20 April 1984 to assess the physical condition of the south mooring dolphin at H. E. Holt after the completion of the above water repairs

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conducted by the Navy Communications Station itself in summer 1983. We conducted an on-site inspection of the facility using divers from the Royal Australian Navy (RAN) in August, 1984. All the connections below the waterline were cleaned to bare metal and the lengths and widths of all visible cracks were determined and recorded. The original records drawings, the previous diver inspection data, and our field measurements of the structure form the data base for models of both the as-built structure and the revised structure.

This dolphin, as well as the other structures at the Point Murat Navy Pier facility, was designed and constructed in the early 1960's. Its intended use is to resist mooring line loads from fuel or cargo vessels mooring at the pier. These loads are shared by the two mooring dolphins, two breasting dolphins and the pier itself. The dolphin is a four sided tubular steel template structure, approximately 50 feet tall, 30 feet wide at the base and 20 feet wide at the top. It rests in 35 feet of seawater near the mouth of Exmouth Gulf in Western Australia. Tubular steel piles driven through the jacket legs into the seafloor anchor the structure in place.

## THREE. STRUCTURAL ANALYSIS INPUTS

### 3.1 SACS III COMPUTER PROGRAM

The following description of the SACS III program and its capabilities are taken directly from the SACS III instruction manual (Ref. A).

> "Engineering Dynamics, Inc. has developed the SACS System of program software which is offered for public use on a royalty basis on several data service bureau computers....SACS consists of several compatible structural analysis programs which are interfaced to each other to eliminate the requirement, but not the ability, for user interaction with the output of one program before input to another....The system consists of input generators, solution programs and posts processors."

> "SEASTATE generates static and dynamic load data simulating the environment for subsequent SACS analysis. Loads due to waves, buoyancy, wind, current and dead loads are calculated....The program generates wave data using Airy, Stokes 5th Order Theory, Stream Functions Wave Theory or the user can use the card input option to describe an arbitrary wave....Current is described by a velocity versus elevation table....Wind loading can be described as either a velocity or a pressure level and the direction need not be the same as the wave or current. In addition the wind load can vary with elevation according to ABS rules if the user selects this option."

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"SACS III is a large capacity, general purpose, linearly elastic, static structural analysis program....Program output consists of element internal loads, deflections, reactions, and stiffness and internal loads matrices for subsequent analysis....SACS III enables the engineer to perform analyses of large, complex structural systems."

"JOINTCAN is an in-stream post processor program which performs punching shear analysis according to April or November 1977 API RP2A code. Joints having multiple intersecting tubular members are analyzed with the program automatically determining which members are chords."

SACS III is rapidly replacing the well known and popular program STRUDL for offshore structural designs calculations. Its corporate users include Gulf and Texaco. The Norwegian government has approved SACS III for North Sea applications.

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## 3.2 ANALYSIS CRITERIA

Virtually all of the members of this structure consist of tubular steel sections. Due to their symmetrical shape, the point of maximum stress due to bending and axial loads may lie anywhere on the circumference of the member, depending on the magnitude of the bending moments. SACS finds a moment resultant and then calculates the combined stresses in the member at the location of the resultant.

The maximum shear stress in a member is found in a similar manner. The shear stress due to the shear force resultant is found and added to the torsional shear stress.

SACS utilizes the allowable stress criteria found in the Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, API RP 2A - ninth edition (Ref. B).

Unity checks are defined as the ratio of actual to allowable stresses in a member or joint based on the appropriate code criteria for the stress condition applied. A value of 1.0 represents the maximum stress allowed by the codes. Any greater value corresponds to a reduction in the factor of safety. Safety factors range from 2.5 for shear to 1.5 for bending alone.

We grouped the unity check values at each joint and within each member of the structure into three groups. Unity checks values between 0.0 and 1.0 indicate ideal stress conditions.

Values between 1.0 and 1.5 indicate stresses greater than those allowed by the appropriate codes. The steel is approaching yield. We cannot define and predict the exact point of failure of a member or joint by stress criteria alone; steel has a great deal of reserve load capacity after theoretical yield has been reached. How stresses are redistributed after plastic deformation begins largely determines whether yielding will continue until the member fails. We interpret unity check values between 1.0 and 1.5 to indicate high stresses with yielding possible. No stronger conclusion is warranted due to the inaccuracies of our model, the variation in materials and the inexactness of the formulas applied.

Unity check values greater than 1.5 represent stresses significantly above code limits and usually above yield. We consider this to represent serious overstressing of a joint or member and is likely to result in a failure.

JOINTCAN converts member internal stresses to a local coordinate system and analyses the joint for punching shear. Unity checks are based on allowable punching shear stress.

Initially we had hoped that the deflections calculated for the structure in response to loads would serve as a good indicator of its condition, especially on a long term basis. However, the predicted above water deflections of both the as-built structure and the revised structure are all less than one inch. Also, the difference in deflections between various stages of progressive collapse of the structure are relatively small. In our view, meaningful evaluation of measured deflections would be expensive and inconclusive. Consequently, no further discussion of deflections is contained in this report.

## FOUR. STRUCTURAL ANALYSIS INPUTS

### 4.1 ENVIRONMENT

The goal in selecting environmental load cases for consideration was to identify the most severe combinations of wind, waves and current likely to act on the structure both during mooring operations and in a typical hurricane.

Standard operating procedure at the Point Murat Pier facility is for a vessel moored at the pier to leave its moorings when winds reach 30 knots. We recognize that storm winds approach quickly and that the vessel may not be capable of getting underway until winds have worsened significantly. We assumed that a ship may still be moored in 50 knot winds. Further this wind is capable of coming from any direction.

The wave modeled in the operational environment is generated by a 50 knot wind. Based on the maximum local fetch of 58 nautical miles shown in figure 4-1, we calculated the deep water wave height and period using the latest edition of the <u>Shore Protection Manual</u> (Ref. C). Shoaling effects were determined using Dean's method to yield a 14.13 feet wave height and an 8.76 second period. This wave will not break in 35 feet of seawater. Refraction was not investigated because

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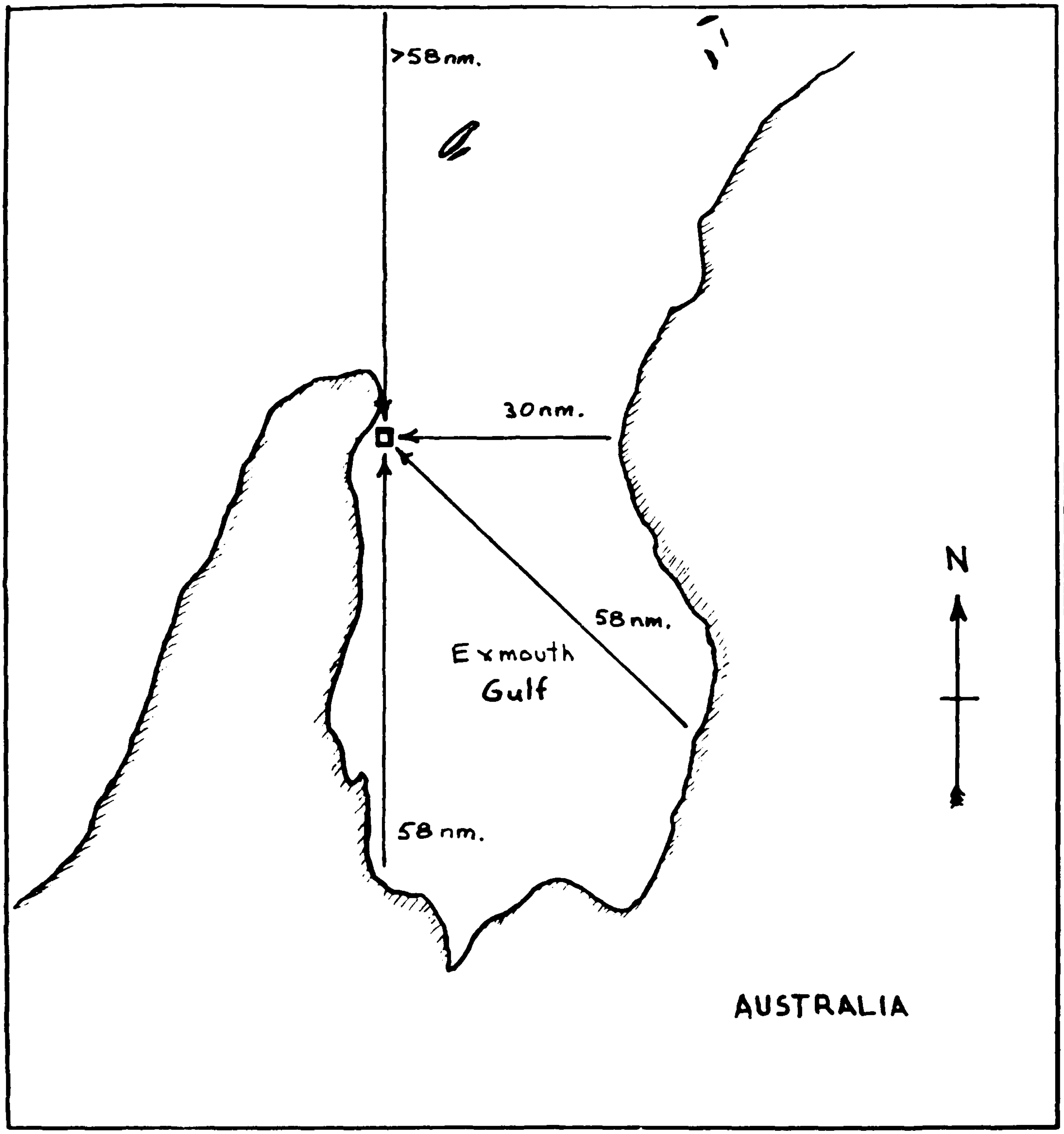


FIGURE 4-1
APPROXIMATE WAVE
FETCH DISTANCES

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bathymetric profiles were not available. Appendix B contains the wave calculations for all the environments considered.

Station personnel and RAN divers have described a strong ebb tide current of about four knots from the south alternating with a weaker flood current of about one knot from the north. The most severe environmental loads occur when the wind, waves and current all are out of the south.

The geometry of mooring a vessel at the pier is shown in figure 4-2. We assume that all lateral forces on the ship are resisted by either the pier or the breasting and spring lines. Longitudinal forces are resisted by the bow and stern lines to the north and south mooring dolphins respectively. We computed the mooring line forces for wind speeds up to 50 knots combined with the appropriate wave heights and a four knot current. These calculations are contained in Appendix A.

For the "survival condition" environment, we chose to model a typical hurricane since Exmouth Gulf lies in a hurricane belt. No statistical data was collected and analyzed to determine the frequency, duration or intensity of large storms at this site.

Hurricane winds can come from any direction. Waves on the other hand are severely fetch limited by the proximity of land on the west and east. The current is unaffected by hurricane action, therefore the four knot current from the south dictates that the largest forces on the structure will occur when a storm strikes from the south.

## 4.2 AS BUILT STRUCTURE - BEFORE COLLISION

Appendix B contains sketches generated by the program EZ-PLOT from the SACS input files and amended to show key dimensions of the as-built structure.

We took the dimensions of the structural members from the record drawings provided by the facility. For modeling purposes, we considered the dolphin to be two structures; one inside another. The outer jacket template is modeled with its full surface area subject to environmental forces. No environmental forces are applied to the inner pile structure.

The piles are linked to the template in several places. At the 600 level, where they are joined by a strong weld, we modeled the connections with all six degrees of freedom restrained from movement. At each level of horizontal bracing, lateral loads alone are transmitted between the piles and jacket. Therefore, we modeled restraints on translations normal to the pile axis. At the base of the jacket, where the pile and jacket are grouted together, we created an equivalent single section with a steel area equal to the sum of the individual areas and a section modulus appropriate for the two tubular members acting together.

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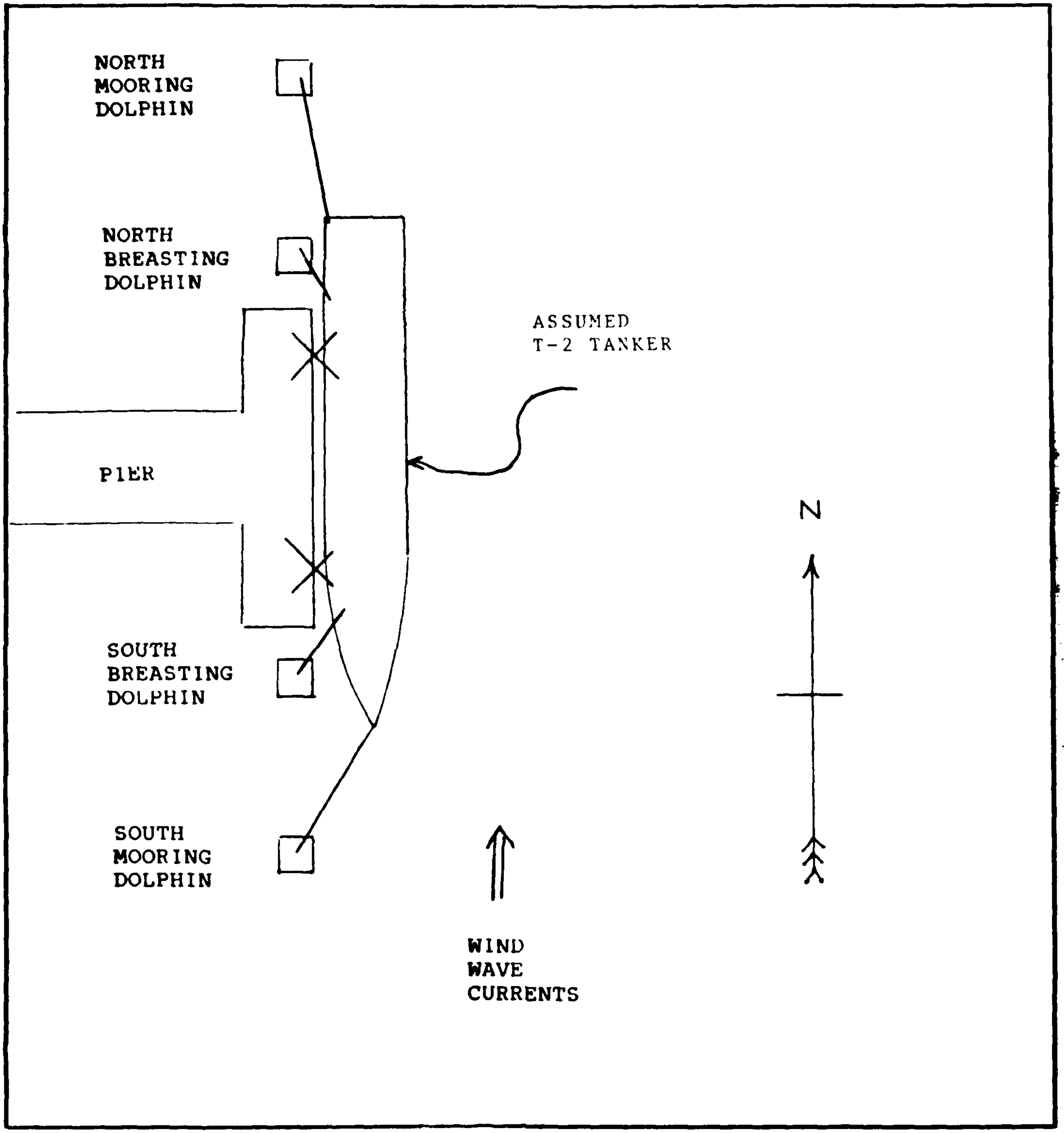


FIGURE 4-2
MOORING GEOMETRY



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The piles extend for 20 to 30 feet into the limestone bottom. A point of fixity was assumed to exist 10 feet below the mudline.

## 4.3 REVISED MODEL - AFTER COLLISION AND INITIAL REPAIR

Divers from United States Salvage Association, Inc. inspected the south mooring dolphin at the request of the Admiralty Division, Office of the Judge Advocate General on 21 December 1982, 12 days after the collision with the M. V. "SARGODHA". Details of their inspection are found in reference D. Additional information was gained from CHESNAVFACENGCOM'S underwater inspection of the dolphin conducted in August, 1984 following the completion of above water repairs to the structure. In some cases the data from the two inspections differed slightly. Conflicts were settled by relying more heavily on the more recent CHESNAVFACENGCOM data.

Appendix C contains sketches of the revised structural geometry and a description of the damage modeled. The overall shape of the dolphin was severely distorted by the collision. The distortion is least severe at the base. At the 400 level and 500 level, near and above the waterline, the original symmetry is grossly distorted.

One category of damage, that of severed connections, was very simple to model. For example, the horizontal brace on the 300 level at the west end of the north face is totally separated from its connection. This is modeled by allowing rotations and deflections of the member in all directions at this point.

Each cracked weld identified by the divers is unique. Unfortunately creating individual models for each joint was too great a task to consider here. Additionally, insufficient data was available to make such models very accurate. Therefore, we created three categories within which we could classify all the cracked joints.

The first category consists of joints in which the weld is not cracked or is cracked for less than one third of the joints total circumference. Here we modeled no reduction in strength.

The second category consists of joints in which the evidence indicates that between one third and two thirds of the connection's circumference is cracked. Here we modeled a weakened member. An additional node was inserted on the member five feet from the end. Between this new node and the jacket we halved the original wall thickness.

The ramifications of this substitution are numerous. Principally the replacement segment maintains the stiffness of the structure at low loads while allowing for greater deflections at higher loads. We recognize that cracked welds fail in a sudden brittle manner. This threshold load could not

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be determined with the tools we have available, nor could the SACS program analyze a connection which exists at one stress and has failed at another without repeated manual correction and reiteration.

The third category of cracked joints consists of those in which cracks were found to exceed two thirds to the circumference of the connection. Here we considered the joint to be severed; the remaining steel must be dangerously weakened.

In several instances divers reported punching shear jacket failure. To account for the jacket's buckled conditions, we freed the connections of adjoining jacket sections at these locations to allow for translations along the axis of the jacket. Translation of brace members normal to the jacket was believed to be restrained unless the connections were cracked and released according to the above criteria.

On the north face of the structure, where the collision occurred, the jacket is crushed against the pile. No evidence shows the pile to be buckled. Here we replaced the jacket section in the model with a section having the same cross sectional area but a reduced moment of inertia.

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# FIVE. STRUCTURAL ANALYSIS RESULTS

## 5.1 AS-BUILT MODEL

In the operational environmental, the as-built structure was found to have no overstressed members, i.e., no members with unity check values greater than 1.0. The JOINTCAN analysis found no joints to be overstressed in the operational environment as well.

For the survival conditions, again no members were indicated to be overstressed. However JOINTCAN identified ten overstressed joints (unity checks values greater than 1.0). The location and magnitude of these overstresses is shown in figure 5-1. No joints were stressed to unity check values greater than 1.5.

## 5.2 REVISED MODEL

The revised structure also endures the operational environment without any overstressed members. The JOINTCAN routine found just two joints we can consider overstressed. Their location and degree of stress is shown in figure 5-2.

The survival environment induces far greater stresses in the revised structure than in the as-built. SACS identified four overstressed members in this harsh environment. The positions and unity check values of these over stressed members are shown in figure 5-3. None of the values are greater than in 1.5.

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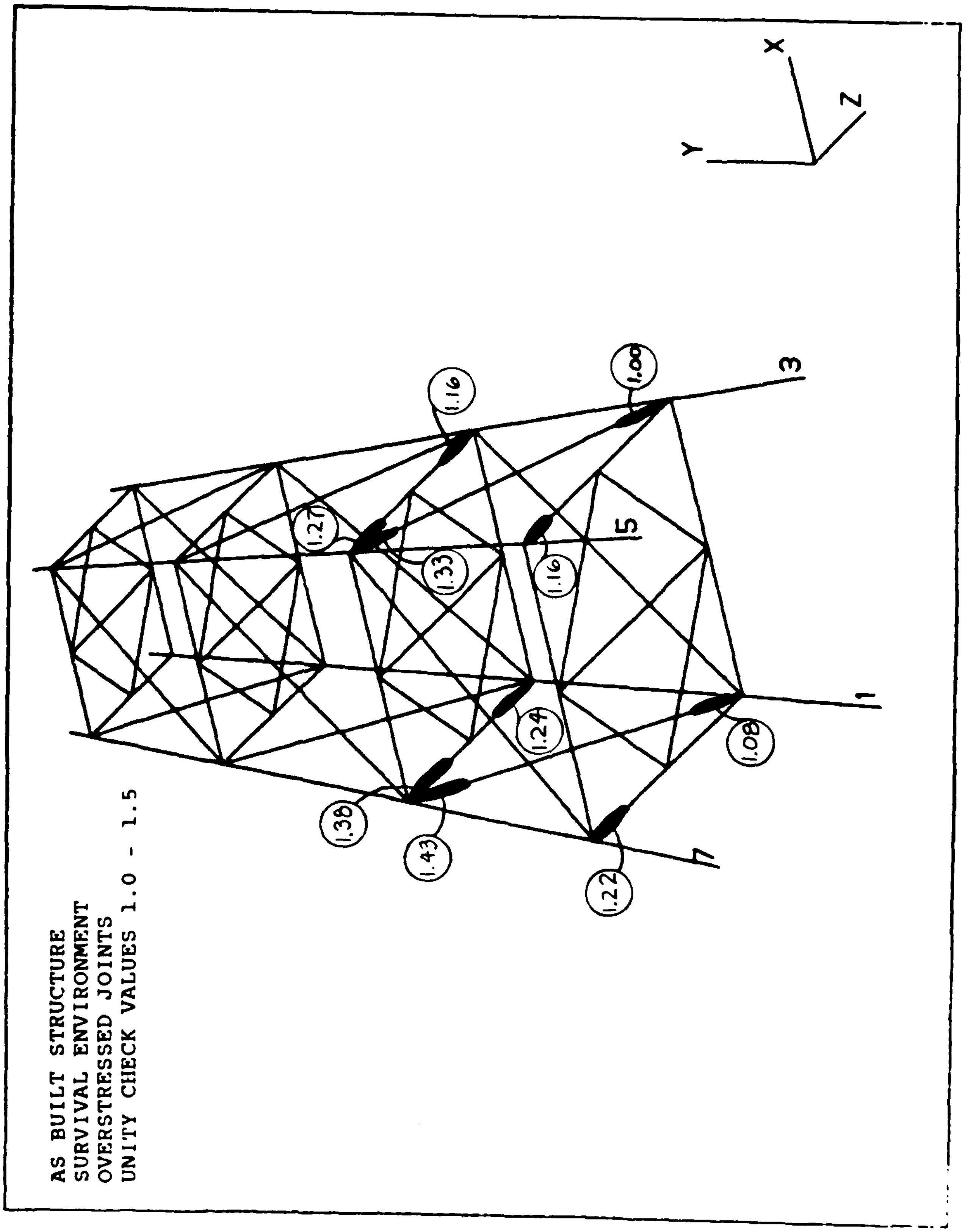


FIGURE 5-1

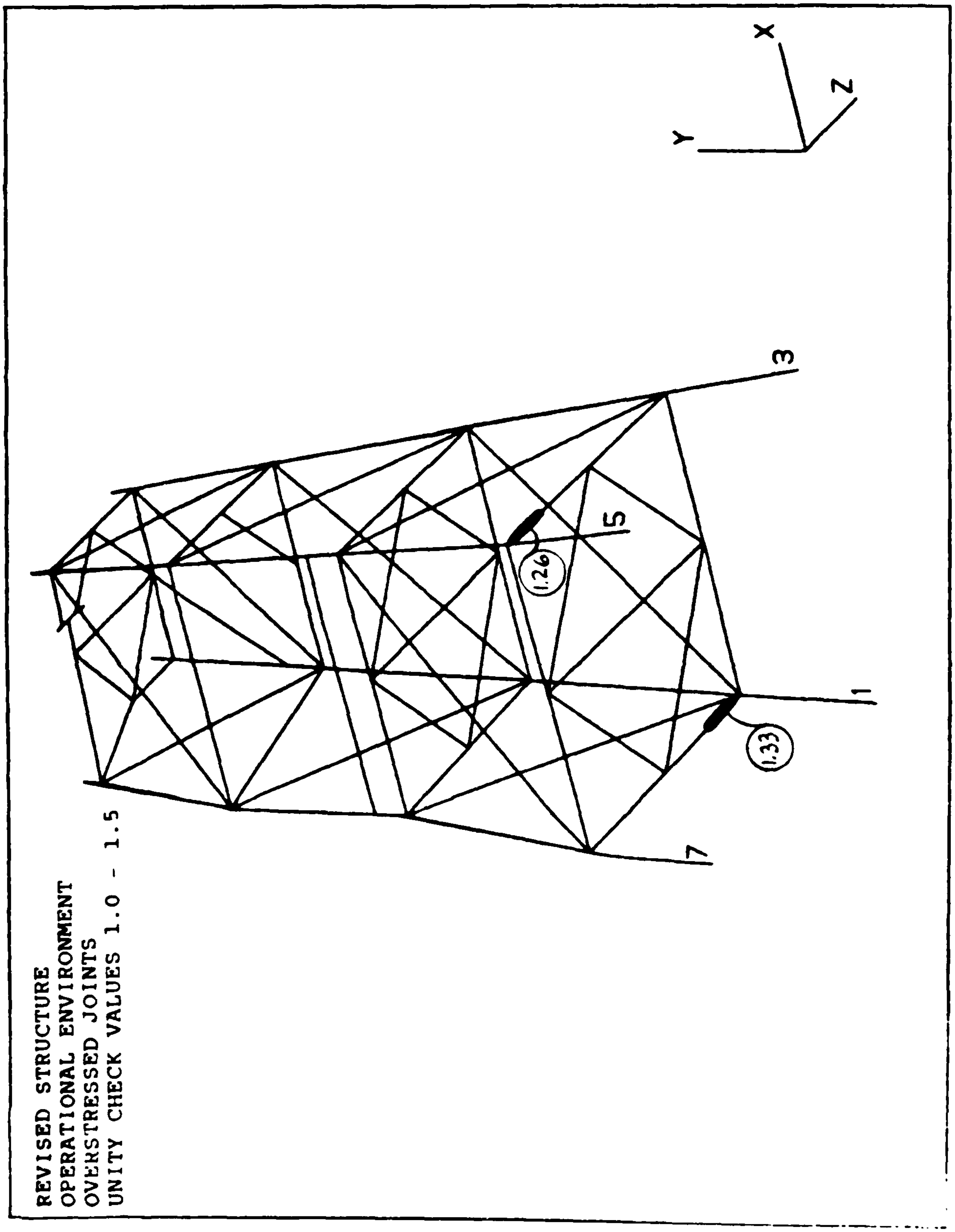


FIGURE 5-2

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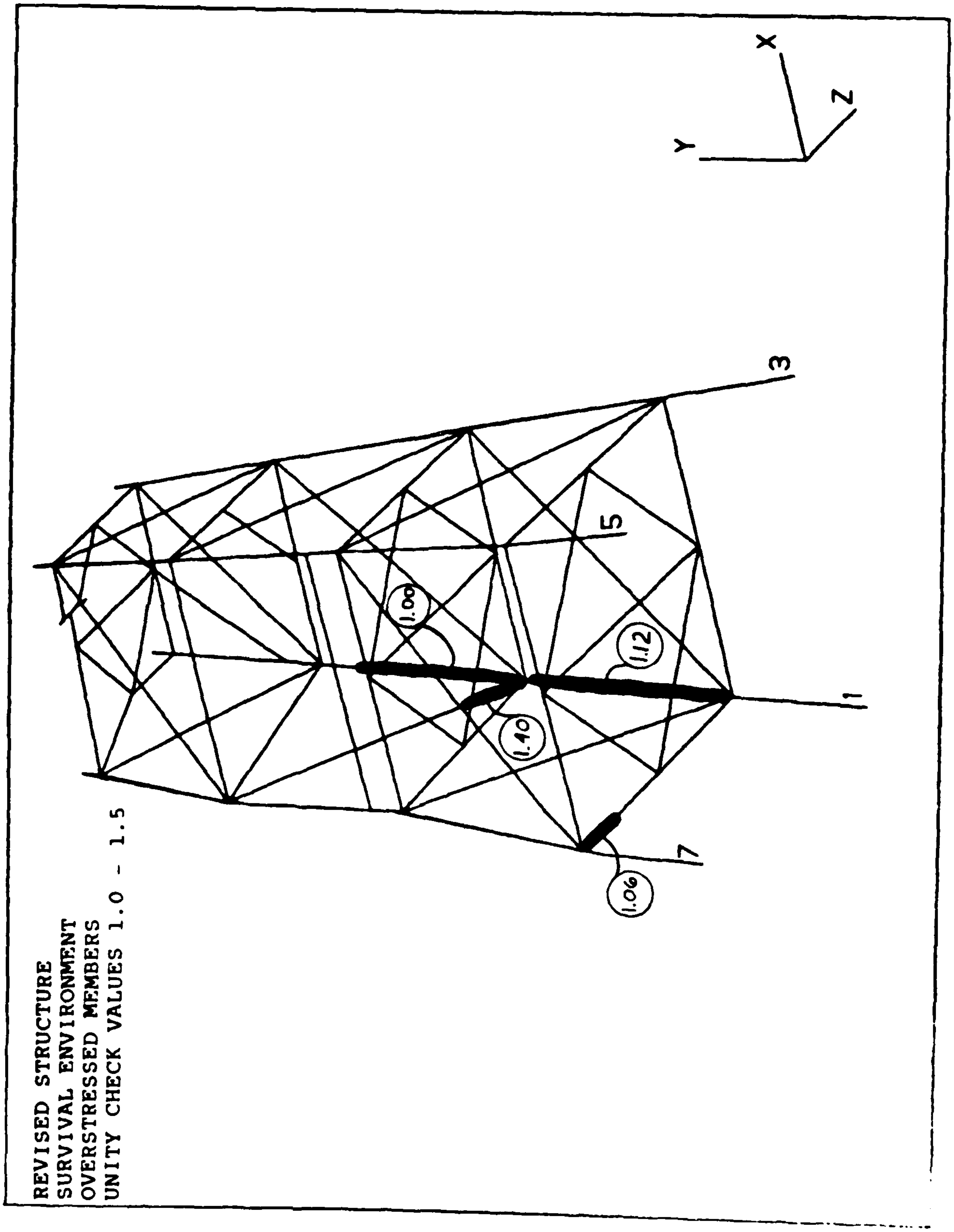


FIGURE 5-3

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The revised structure has 13 overstressed joints in the hurricane environment. Five of these fall into the range of unity check values between 1.0 and 1.5. Eight have unity check values greater than 1.5; ranging to as high as 3.79. The locations of these overstresses and their magnitudes are shown in figure 5-4 and 5-5.

After determining that the dolphin would be overstressed in a hurricane environment, we sought to estimate the magnitude of a storm which would just start to overstress the structure's joints. We examined the structure's response to winds of 50, 60, 70, 80, 90 and 10C knots. Table 5-1 shows wind speed vs maximum unity check values for all of the structure joints. We observed from figure 5-6 that a storm with sustained 64 knot winds would stress at least one joint to a unity check value of 1.5 (indicating a failure).

REVISED STRUCTURE - LIMITING STORM

| WIND SPEED (KNOTS) | WAVE HEIGHT (FT) | MAXIMUM UNITY CHECK VALUE |
|---|---|---|
| 50 | 14.14 | 0.721 |
| 60 | 17.05 | 1.083 |
| 70 | 20.37 | 2.216 |
| 80 | 24.16 | 3.319 |
| 90 | 25.81 | 3.709 |
| 100 | 25.81 | 3.793 |

Table 5-1

Thus far in each simulation we have considered the largest static force on the structure resulting from the superposition of loads from wind, current, mooring loads and a single wave. We expect that when a hurricane strikes in Exmouth Gulf it will develop many waves comparable to the survival condition wave used here. The effect of a series of storm waves striking the structure was approximated by repeatedly applying the design wave to the model and correcting the model for accumulated damage.

To model the effect of high stresses, we "released" joints when the unity check value exceeded a threshold value. A released joint is created by removing all the fixity between the end of the brace member and the jacket. We used a threshold unity check value of 1.5 for the first series of waves applied. This is the same overstress criteria used previously to identify joints stressed beyond yield and represents a safety factor of 0.66. As a measure of the sensitivity of our model to this threshold value, a second series of waves was applied using a

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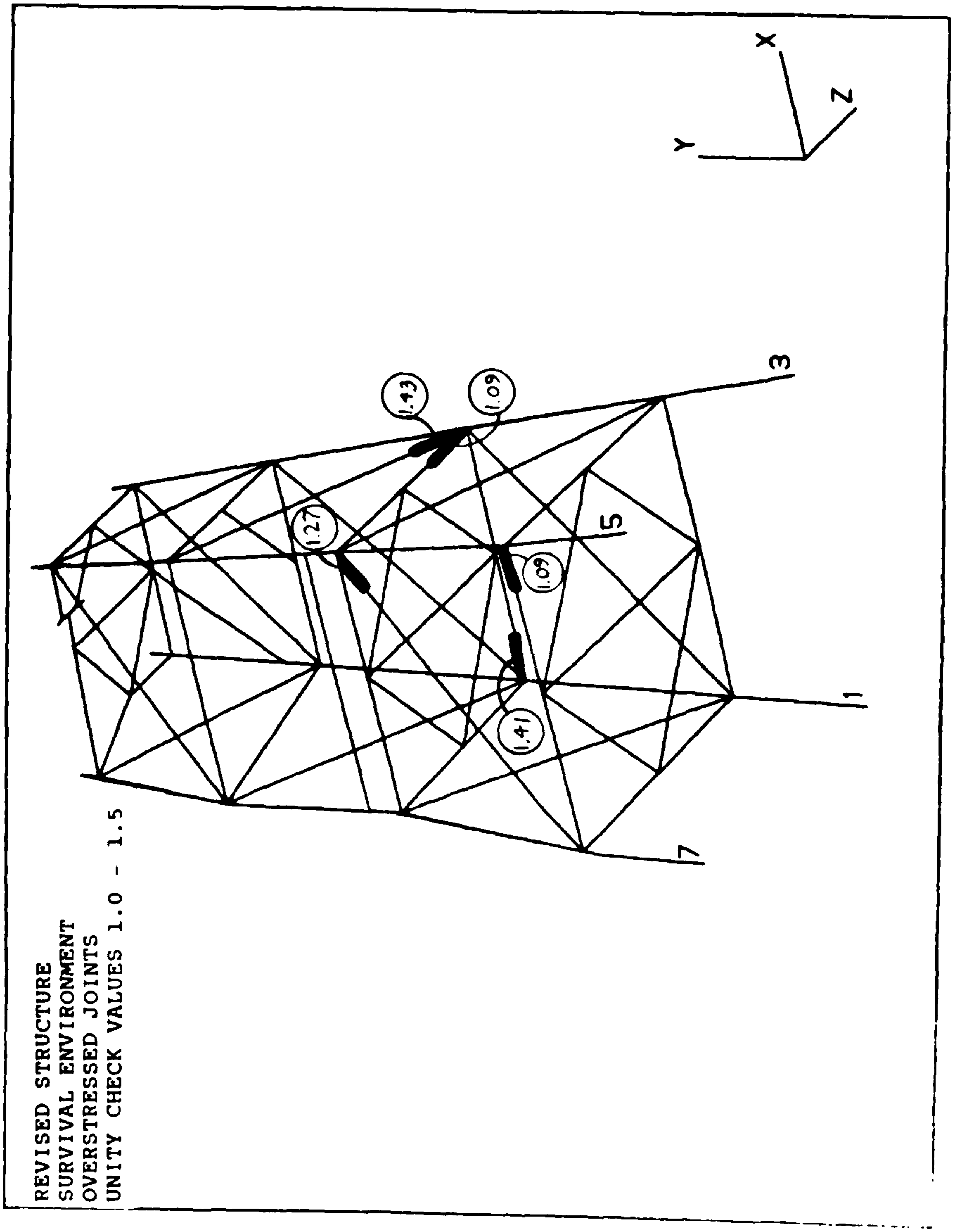


FIGURE 5-4

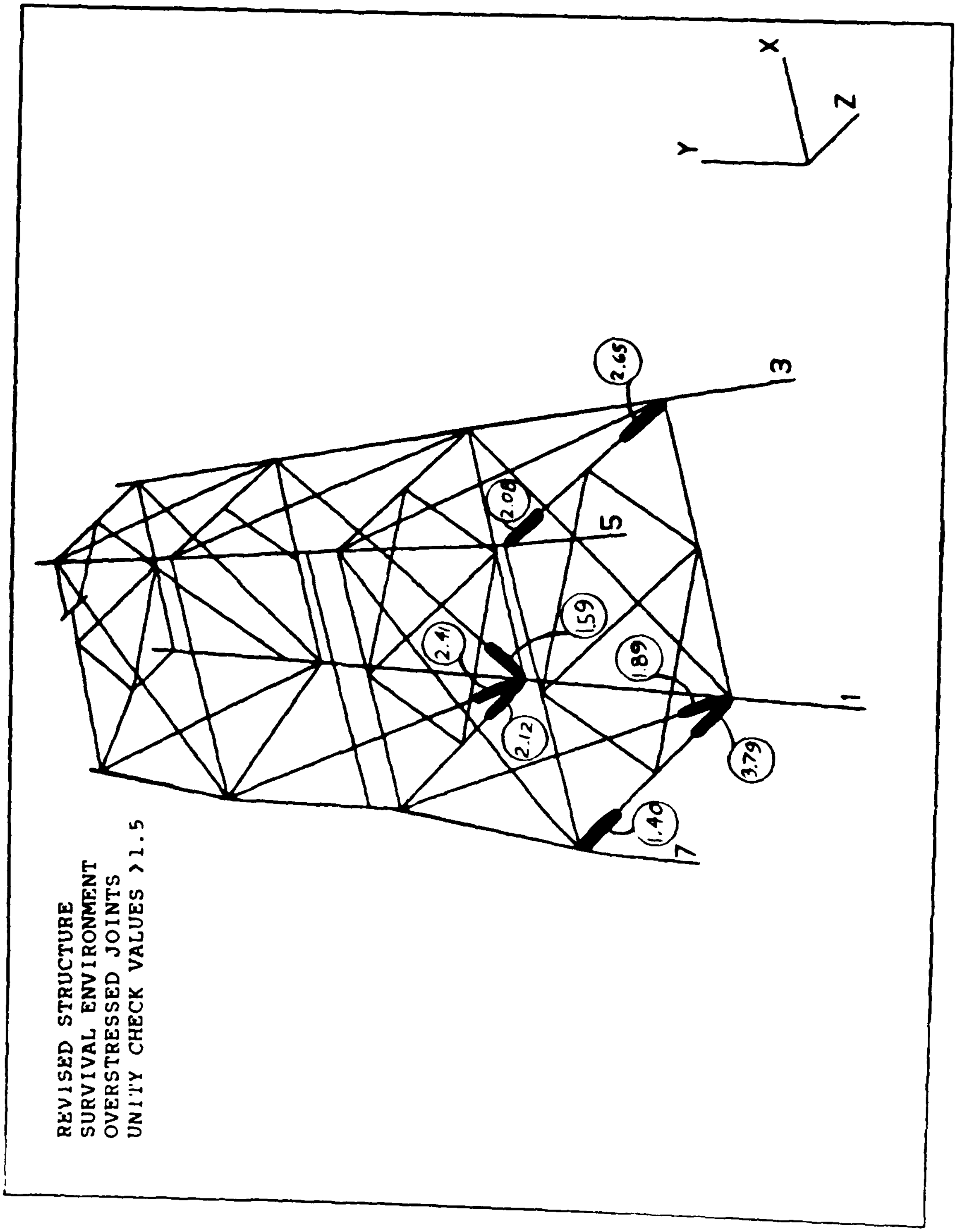


FIGURE 5-5



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REPRODUCED AT GOVERNMENT EXPENSE

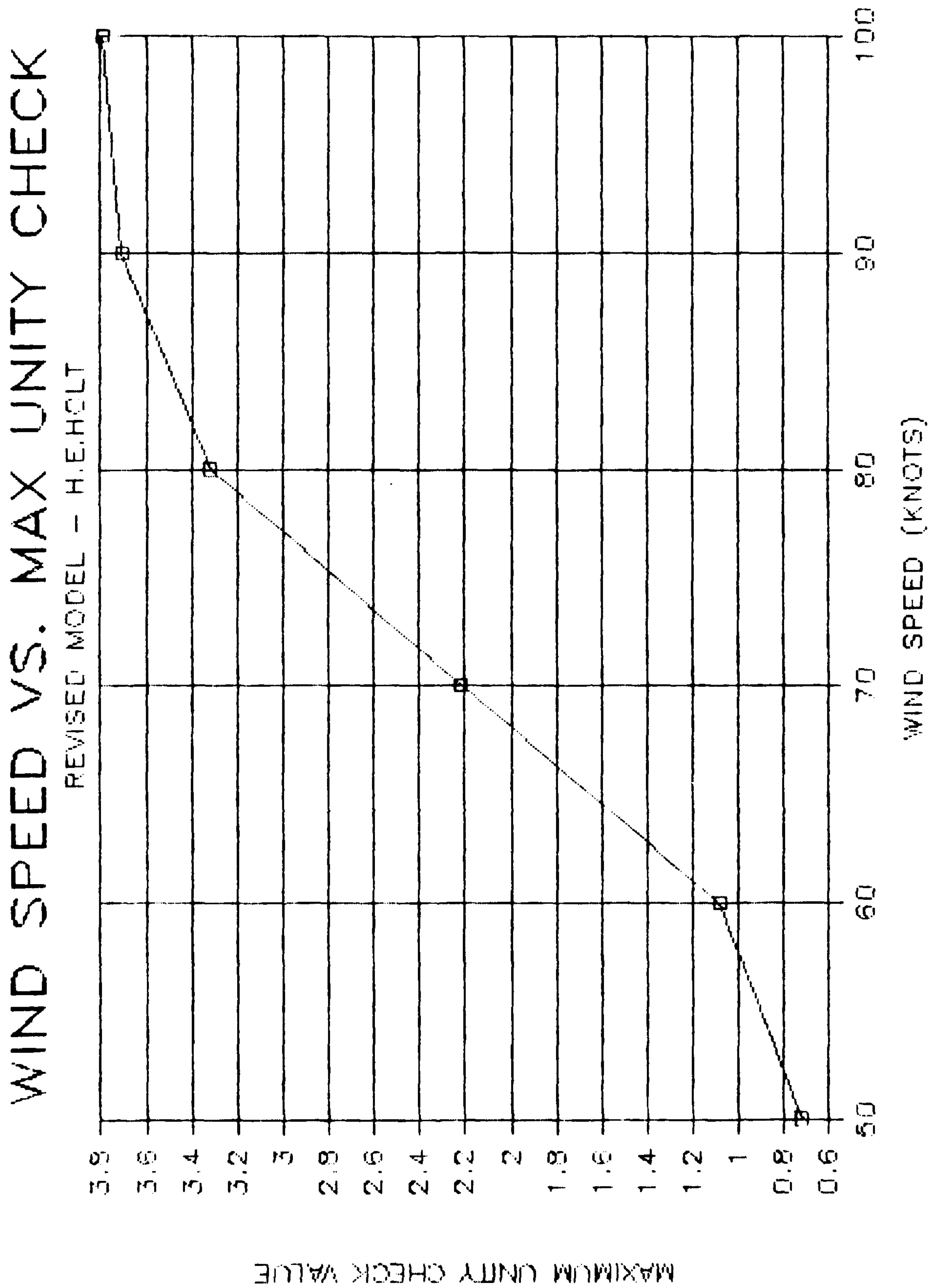


**FIGURE 5-6**

2.5 threshold valve. This is equivalent to requiring joints to fail when the factor of safety falls below 0.4.

The results of these "progressive collapse" simulations are shown in Table 5-2.

The overstresses for the as-built and revised models for both the operational and survival environments are summarized in Table 5-3.

## SIX. CONCLUSIONS

From table 5.3 we can see that the as-built structure experiences overstresses in the joints only in a hurricane environment. Since the ratio of actual stress to allowable stress, as expressed by the unity check value, never exceeds 1.5, we cannot be certain that any joints will fail. No overstressing is indicated at the joints in the mooring environment nor are any overstresses seen in the members themselves in either environment. Therefore we conclude that the south mooring dolphin was designed with adequate strength for both its intended use in a calm environment and for survival in a hurricane.

The above water repairs affected by the facility were successful in that they have restored the structures short term capacity for normal use. Table 5-3 shows that in the operating environment just two joints are overstressed. However the stresses are not high enough for us to conclude that joints will fail. We conclude that normal mooring forces and an environment with sustained winds of 50 knots or lower should not damage the structure, provided no serious deterioration has occurred subsequent to the summer 1984 inspections.

This structure will be dangerously overstressed in a hurricane. The approximate limiting sea consists of 64 knot sustained winds and the approximately 20 feet high waves associated with it. In such a storm, joint overstresses are predicted to be sufficient for at least one joint to fail. The unity check value of the most stressed joint is 1.5 representing a safety factor of 0.66 for stress.

Further, in 100 knot winds and the associated 26 feet high waves, the same criteria indicate the dolphin will collapse. Each successive wave inflicts more damage to the structure. Even if a more generous standard is applied and joint safety factors are allowed to drop as low as 0.4, the structure will fail at 6 joints after just 4 waves. Therefore, we conclude that the south mooring dolphin must be considered damaged if it experiences sustained winds of 64 knots or greater.

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PROGRESSIVE COLLAPSE - SURVIVAL CONDITIONS - REVISED MODEL

JOINT FAILURE CONDITION: UNITY CHECK > 1.5

| ITERATION | JOINT UNITY CHECK VALUE 1-1.5 | JOINT UNITY CHECK VALUE >1.5 | CUMULATIVE # OF FAILED JOINTS AFTER RUN | PERCENTAGE OF TOTAL JOINTS FAILED |
|---|---|---|---|---|
| 0 | 5 | 8 | 8 | 9 |
| 1 | 9 | 10 | 18 | 20 |
| 2 | 10 | 10 | 28 | 32 |
| 3 | 14 | 2 | 30 | 34 |

JOINT FAILURE CONDITION: UNITY CHECK > 2.5

| ITERATION | JOINT UNITY CHECK VALUE 1-2.5 | JOINT UNITY CHECK VALUE >2.5 | CUMULATIVE # OF FAILED JOINTS AFTER RUN | PERCENTAGE OF TOTAL JOINTS FAILED |
|---|---|---|---|---|
| 0 | 11 | 2 | 2 | 2 |
| 1 | 11 | 3 | 5 | 6 |
| 2 | 14 | 1 | 6 | 7 |
| 3 | 15 | 0 | 6 | 7 |

TABLE 5-2



REPRODUCED AT GOVERNMENT EXPENSE

## OVERSTRESS SUMMARY

### AS BUILT MODEL - BEFORE COLLISION

OPERATING CONDITIONS:

| MEMBERS (SACS) UNITY CHECK VALUE | QUANTITY | JOINTS (JOINTCAN) UNITY CHECK VALUE | QUANTITY |
|---|---|---|---|
| 1.0 - 1.5 | 0 | 1.0 - 1.5 | 0 |
| >1.5 | 0 | >1.5 | 0 |

SURVIVAL CONDITIONS:

| MEMBERS (SACS) UNITY CHECK VALUE | QUANTITY | JOINTS (JOINTCAN) UNITY CHECK VALUE | QUANTITY |
|---|---|---|---|
| 1.0 - 1.5 | 0 | 1.0 - 1.5 | 10 |
| >1.5 | 0 | >1.5 | 0 |

### REVISED MODEL - AFTER COLLISION

OPERATING CONDITIONS:

| MEMBERS (SACS) UNITY CHECK VALUE | QUANTITY | JOINTS (JOINTCAN) UNITY CHECK VALUE | QUANTITY |
|---|---|---|---|
| 1.0 - 1.5 | 0 | 1.0 - 1.5 | 2 |
| >1.5 | 0 | >1.5 | 0 |

SURVIVAL CONDITIONS:

| MEMBERS (SACS) UNITY CHECK VALUE | QUANTITY | JOINTS (JOINTCAN) UNITY CHECK VALUE | QUANTITY |
|---|---|---|---|
| 1.0 - 1.5 | 4 | 1.0 - 1.5 | 5 |
| >1.5 | 0 | >1.5 | 8 |

TABLE 5-3



REPRODUCED AT GOVERNMENT EXPENSE

## SEVEN. RECOMMENDATIONS

### 7.1 INITIATE MILCON REPLACEMENT

In any environment, the remaining useful lifetime of the structure has been drastically reduced as a result of the collision by MV SARGODHA. We recommend immediate initiation of procedures for a MILCON replacement of this dolphin.

### 7.2 INSPECT FREQUENTLY

Due to the 25 year fatigue history of this dolphin, crack propagation in the joints is faster than in a new structure. Additionally the presence of numerous cracks resulting from the collision has created many areas of concentrated stress. Diver inspection is a viable method for monitoring crack growth. Other methods exist to monitor crack growth such as instrumenting the dolphin with strain gauges and recorders. This requires expensive equipment investment and subsequent data analysis. This does not appear to be cost effective for a structure with such a finite life expectancy. We recommend divers inspect the structure by cleaning it down to bare metal and measuring cracks on a semi-annual basis.

### 7.3 CONTINUE CURRENT USE

In the absence of evidence of new damage, the structure has adequate strength for use in mooring supply vessels in calm seas. All lines must be dropped if winds exceed 50 knots. We recommend continued use of the structure for its intended purpose as is ordinarily practiced at H.E. HOLT.

### 7.4 MONITOR ENVIRONMENT

The dolphin will experience damage when storms with wind speeds 64 knots or greater inflict 20 feet high seas on it. Waves with enough energy to damage the dolphin are possible without a direct hit by storm winds. If waves overtop the top of the structure, regardless of the associated wind, damage is likely. We recommend continuous monitoring of wind speeds and wave heights in the near vicinity of the south dolphin especially in foul weather.

### 7.5 STOP USE AFTER LARGE STORM

The dolphin must be considered damaged after waves 20 feet high or higher strike. Damage is expected after a storm with sustained 65 knot winds passes through the Gulf. We recommend use of the dolphin be immediately discontinued after the dolphin has been overtopped by waves approximately 20 feet high. Use should not be resumed until the dolphin has been inspected and reevaluated.

REPRODUCED AT GOVERNMENT EXPENSE

## EIGHT. REFERENCES

A. Engineering Dynamics Inc., SACS III User's Guide, USA, 1979.

B. American Petroleum Institute, API Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms, API RP 2A, tenth edition, March 1979.

C. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Corps of Engineers, Shore Protection Manual, forth edition, 1983.

D. United States Salvage Association, Inc., report of inspection of Harold E. Holt pier, January 1983.

REPRODUCED AT GOVERNMENT EXPENSE

# APPENDIX A: ENVIRONMENTAL FORCE CALCULATIONS

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION | PROJECT: |
|---|---|
| Naval Facilities Engineering Command NDW | Station: |
| DISCIPLINE | E S R: Contract: |
| Calcs made by: date: | Calculations for: |
| Calcs ck'd by: date: | |

MOORING FORCES

$A_0 - 57$ (T-2 TANKER)

| | | | FULL | 1/2 | LIGHT |
|---|---|---|---|---|---|
| $L_W = 544'$ | | $A_s =$ | $17{,}050\ ft^2$ | $24{,}150\ ft^2$ | $27{,}700\ ft^2$ |
| $L_{OA} =$ | | $A_e =$ | $3{,}900\ ft^2$ | $4{,}900\ ft^2$ | $5{,}400\ ft^2$ |

LATERAL WIND LOAD $= F_{yw} = C_{yw}(1/2)\,\rho_w V_w^2 A_s$

$C_{yw} = 1.0$ @ $\theta = 90°$

$V_w = 50$ knots $= 50 \times 1.688 = 84.4$ ft/sec

$\rho_w = 0.00237$

$F_{yw} = 1.0 \times 1/2 \times 0.00237 \times (84.4)^2 \times 24{,}150$

$= 203{,}854$ lbs

LONGITUDINAL WIND LOAD $= F_{xw} = C_{xw}(1/2)\,\rho_w V_w^2 A_e$

$F_{xw} = 0.9 \times 1/2 \times 0.00237 \times (84.4)^2 \times 4900$

$= 37226$ lbs.

CURRENT @ 4 knots $= 4 \times 1.688 = 6.752$ ft/sec

$F_{xc} = (1/2)\,\rho_c V_c^2 \left(C_{xcA} \Sigma \frac{B}{LWL} + C_{xcb} A_b\right)$

$\theta_c = 0°$ , $C_{xcb} = C_{yc} = 0$



GPO 885-053

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION<br>Naval Facilities Engineering Command NDW<br>DISCIPLINE | PROJECT: ______<br>Station: ______<br>E S R: ______ Contract: ______<br>Calculations for: ______ |
|---|---|
| Calcs made by: ______ date: ______<br>Calcs ck'd by: ______ date: ______ | |

for normal ships $S = 0.95\left[(1.7 \times T \times LWL) + \frac{35\,D}{T}\right]$

$LWL = 544'$ $\quad D = 13,460$ (lt)

$T = 18.5'$

$S = 0.95\left[1.7 \times 18.5 \times 544 + \frac{35 \times 13,460}{18.5}\right]$

$= 40,445$

$B = 75'$ , $C_{xcn} = 0.35$

$F_{xc} = \frac{1}{2} \times 1.9876 \times (6.752)^2 \times 0.35 \times 40,445 \times \frac{75}{544}$

$= 44210$ lbs

LONGITUDINAL

Total Static Force $= (44,210 + 37,226) = 81,000$ #

Dynamic Amplification Factor $= 4/3$

$4/3 \times 81\,K = 108,000$ #

Note : Earlier calculations yielded 104,000 lbs. The difference is insignificant. The earlier value was used.



GPO 885-653

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION Naval Facilities Engineering Command NDW DISCIPLINE | PROJECT: H E. Holt |
|---|---|
| | Station: |
| | E S R: Contract: |
| Calcs made by: J Hansen date: 20 Dec 1984 | Calculations for: Wave Calculations |
| Calcs ck'd by: I Jones date: | |

SUMMARY

| Wind Speed - (kn) | Wave Height - (ft.) | Period - (sec) |
|---|---|---|
| 50 | 14.13 | 8.75 |
| 60 | 17.05 | 9.30 |
| 70 | 20.37 | 9.79 |
| 80 | 24.16 | 10.24 |
| 90 | 25.80 | 10.65 |

1. These values are recommended for use in the SACS program to analyse the H.E. Holt jacket structure.



GPO 888-653

REPRODUCED AT GOVERNMENT EXPENSE

| **CHESAPEAKE DIVISION** Naval Facilities Engineering Command NDW DISCIPLINE | PROJECT: H.E. Holt |
|---|---|
| Calcs made by: J. Hansen date: 20 Dec 1984 | Station: |
| Calcs ck'd by: date: | E S R: Contract: |
| | Calculations for: |

Fetch = 58 nm

| (kn) | WAVE HEIGHT-(ft) | PER |
|---|---|---|
| | 0.00 | 0.00 |
| 2 | .57 | 2.99 |
| 4 | 1.13 | 3.77 |
| 6 | 1.70 | 4.32 |
| 8 | 2.26 | 4.75 |
| 10 | 2.83 | 5.12 |
| 12 | 3.39 | 5.44 |
| 14 | 3.96 | 5.73 |
| 16 | 4.52 | 5.99 |
| 18 | 5.09 | 6.23 |
| 20 | 5.65 | 6.45 |
| 22 | 6.22 | 6.66 |
| 24 | 6.78 | 6.85 |
| 26 | 7.35 | 7.04 |
| 28 | 7.91 | 7.22 |
| 30 | 8.48 | 7.38 |
| 32 | 9.04 | 7.54 |
| 34 | 9.61 | 7.70 |
| 36 | 10.17 | 7.85 |
| 38 | 10.74 | 7.99 |
| 40 | 11.30 | 8.13 |
| 42 | 11.87 | 8.26 |
| 44 | 12.43 | 8.39 |
| 46 | 13.00 | 8.51 |
| 48 | 13.56 | 8.64 |
| 50 | 14.13 | 8.75 |
| 52 | 14.69 | 8.87 |
| 54 | 15.26 | 8.98 |
| 56 | 15.82 | 9.09 |
| 58 | 16.39 | 9.20 |
| 60 | 16.95 | 9.30 |
| 62 | 17.52 | 9.40 |
| 64 | 18.08 | 9.50 |
| 66 | 18.65 | 9.60 |
| 68 | 19.21 | 9.70 |
| 70 | 19.78 | 9.79 |
| 72 | 20.34 | |
| | 20.91 | |
| | 21.47 | |
| | 22.04 | |



GPO 888-853

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION | PROJECT: H. E. Holt |
|---|---|
| Naval Facilities Engineering Command NDW | Station: |
| DISCIPLINE | E S R: Contract: |
| Calcs made by: J Hansen date: 20 Dec 1984 | Calculations for: |
| Calcs ck'd by: date: | |

Fetch = 58 nm.

| WIND SPEED - (kn) | WAVE HEIGHT - (ft) | PERIOD - (sec) |
|---|---|---|
| 80 | 22.60 | 10.24 |
| 82 | 23.17 | 10.32 |
| 84 | 23.73 | 10.41 |
| 86 | 24.30 | 10.49 |
| 88 | 24.86 | 10.57 |
| 90 | 25.43 | 10.65 |
| 92 | 25.99 | 10.73 |
| 94 | 26.56 | 10.80 |
| 96 | 27.12 | 10.88 |
| 98 | 27.69 | 10.95 |
| 100 | 28.25 | 11.03 |
| 102 | 28.82 | 11.10 |
| 104 | 29.38 | 11.17 |
| 106 | 29.95 | 11.24 |
| 108 | 30.51 | 11.32 |
| 110 | 31.08 | 11.38 |
| 112 | 31.65 | 11.45 |
| 114 | 32.21 | 11.52 |
| 116 | 32.78 | 11.59 |
| 118 | 33.34 | 11.65 |
| 120 | 33.91 | 11.72 |
| 122 | 34.47 | 11.78 |
| 124 | 35.04 | 11.85 |
| 126 | 35.60 | 11.91 |
| 128 | 36.17 | 11.97 |
| 130 | 36.73 | 12.04 |
| 132 | 37.30 | 12.10 |
| 134 | 37.86 | 12.16 |
| 136 | 38.43 | 12.22 |
| 138 | 38.99 | 12.28 |
| 140 | 39.56 | 12.34 |

1. Based upon SPM Vol I p. 3-48, 1984.
Equations 3-33c and 3-34c



GPO 885-653

REPRODUCED AT GOVERNMENT EXPENSE

| | |
|---|---|
| **CHESAPEAKE DIVISION**<br>**Naval Facilities Engineering Command NDW**<br>**DISCIPLINE** | **PROJECT:**<br>**Station:**<br>**E S R:** **Contract:** |
| **Calcs made by:** **date:**<br>**Calcs ck'd by:** **date:** | **Calculations for:** |

Wind Speed = 50 knots $H_s = 14.13$ ft. $T = 8.75$ sec.

$$L_o = 5.12\,T^2 = 5.12\,(8.75)^2 = 392.00 \text{ ft.}$$

$$\frac{h}{L_o} = \frac{35.083}{392.00} = 0.0895$$

$$\frac{H_o}{L_o} = \frac{14.13}{392.00} = 0.0360$$

Fig. 25, Dean, p. 53.

$$\frac{H}{L_o} = 0.036 \quad \Rightarrow \quad H = 14.13 \text{ ft.}$$

---

Wind Speed = 60 kn. $H_s = 16.95$ ft. $T_s = 9.30$ s.

$$L_o = 5.12\,T^2 = 5.12\,(9.30)^2 = 442.83 \text{ ft.}$$

$$\frac{h}{L_o} = \frac{35.083}{442.83} = 0.0792$$

$$\frac{H_o}{L_o} = \frac{16.95}{442.83} = 0.0383$$

Fig. 25, Dean, p. 53

$$\frac{H}{L_o} = 0.0385 \quad \Rightarrow \quad H = 17.05 \text{ ft}$$



GPO 885-653

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION Naval Facilities Engineering Command NDW DISCIPLINE | PROJECT: Station: E S R: Contract: |
|---|---|
| Calcs made by: date: Calcs ck'd by: date: | Calculations for: |

Wind Speed = 70 kn. $H_s$ = 19.78 ft. $T_s$ = 9.79 sec.

$$L_o = 5.12\,T^2 = 5.12\,(9.79)^2 = 490.72 \text{ ft.}$$

$$\left.\begin{aligned} \frac{h}{L_o} &= \frac{35.083}{490.72} = 0.0715 \\ \frac{H_o}{L_o} &= \frac{19.78}{490.72} = 0.0403 \end{aligned}\right\} \text{Fig. 25, } \underline{\text{Dean}}\text{, p. 53.}$$

$$\frac{H}{L_o} = 0.0415 \Rightarrow \underline{\underline{H = 20.37 \text{ ft}}}$$

Wind Speed = 80 kn. $H_s$ = 22.60 ft. $T_s$ = 10.24 s.

$$L_o = 5.12\,T^2 = 5.12\,(10.24)^2 = 536.87 \text{ ft}$$

$$\left.\begin{aligned} \frac{h}{L_o} &= \frac{35.083}{536.87} = 0.0653 \\ \frac{H_o}{L_o} &= \frac{22.60}{536.87} = 0.0421 \end{aligned}\right\} \text{Fig. 25, } \underline{\text{Dean}}\text{, p. 53}$$

$$\frac{H_o}{L_o} = 0.045 \Rightarrow \underline{\underline{H_o = 24.16 \text{ ft.}}}$$



GPO 885-653

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION | PROJECT: |
|---|---|
| Naval Facilities Engineering Command NDW | Station: |
| DISCIPLINE | E S R: Contract: |
| Calcs made by: date: | Calculations for: |
| Calcs ck'd by: date: | |

Wind Speed = 90 kn. $H_s$ = 25.43 ft. $T_s$ = 10.65

$L_o = 5.12\,T^2 = 5.12\,(10.65)^2 = 580.72$ ft.

$$\left.\begin{aligned} \frac{h}{L_o} &= \frac{35.083}{580.72} = 0.0604 \\ \frac{H_o}{L_o} &= \frac{25.43}{580.72} = 0.0438 \end{aligned}\right\}$$ Fig 25, Dean, p.53

$\frac{H}{L_o} = 0.0448 \implies$ Breaking Wave $H_B = 26.04$ ft $>$ H = 25.8 ft

$\therefore$ Use H = 25.8 ft. and T = 10.65

This is the same value for H as in the 100 knot wind case, however, the period is different.

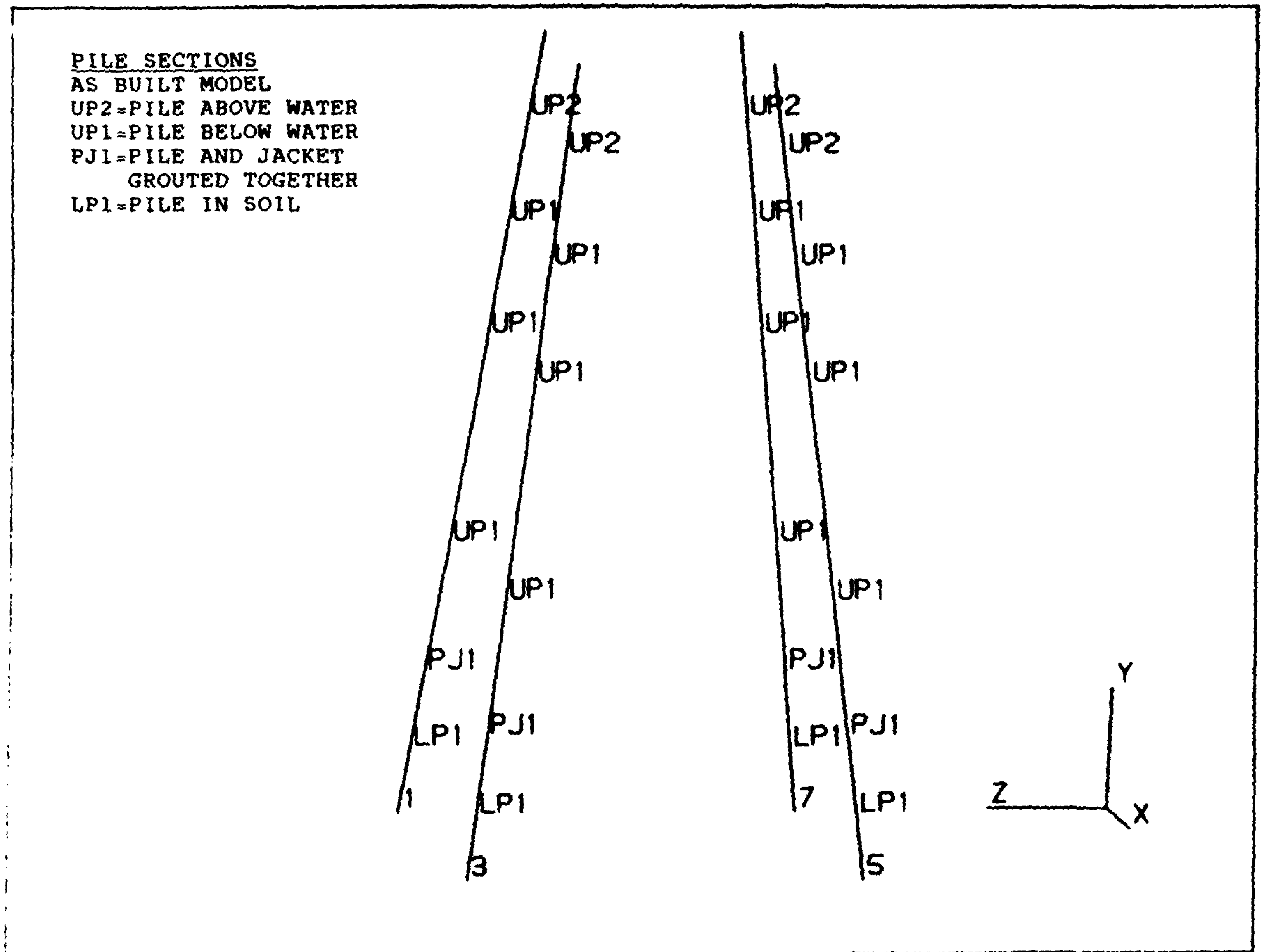


GPO 885-693

REPRODUCED AT GOVERNMENT EXPENSE

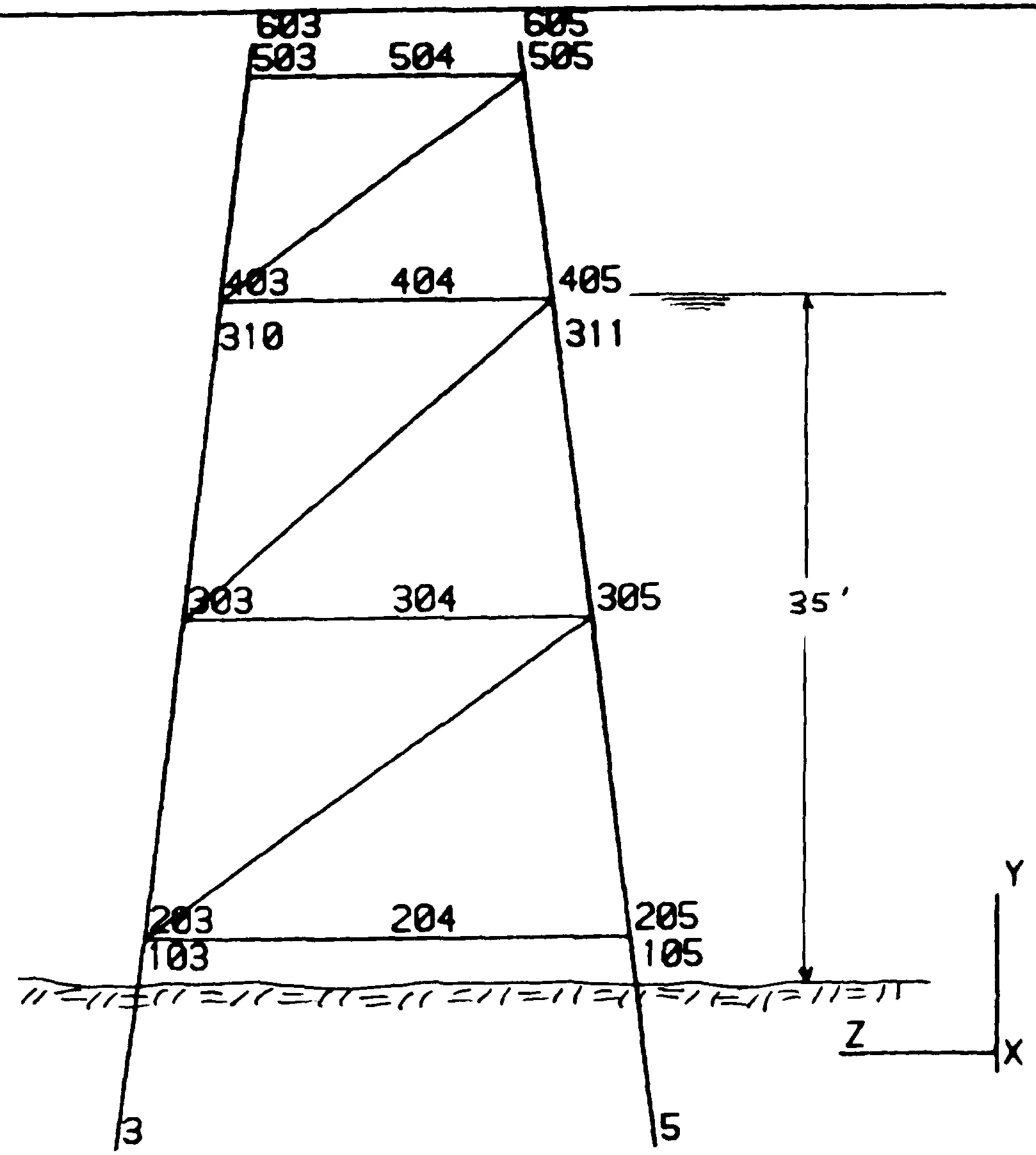
# APPENDIX B: AS-BUILT SKETCHES

REPRODUCED AT GOVERNMENT EXPENSE

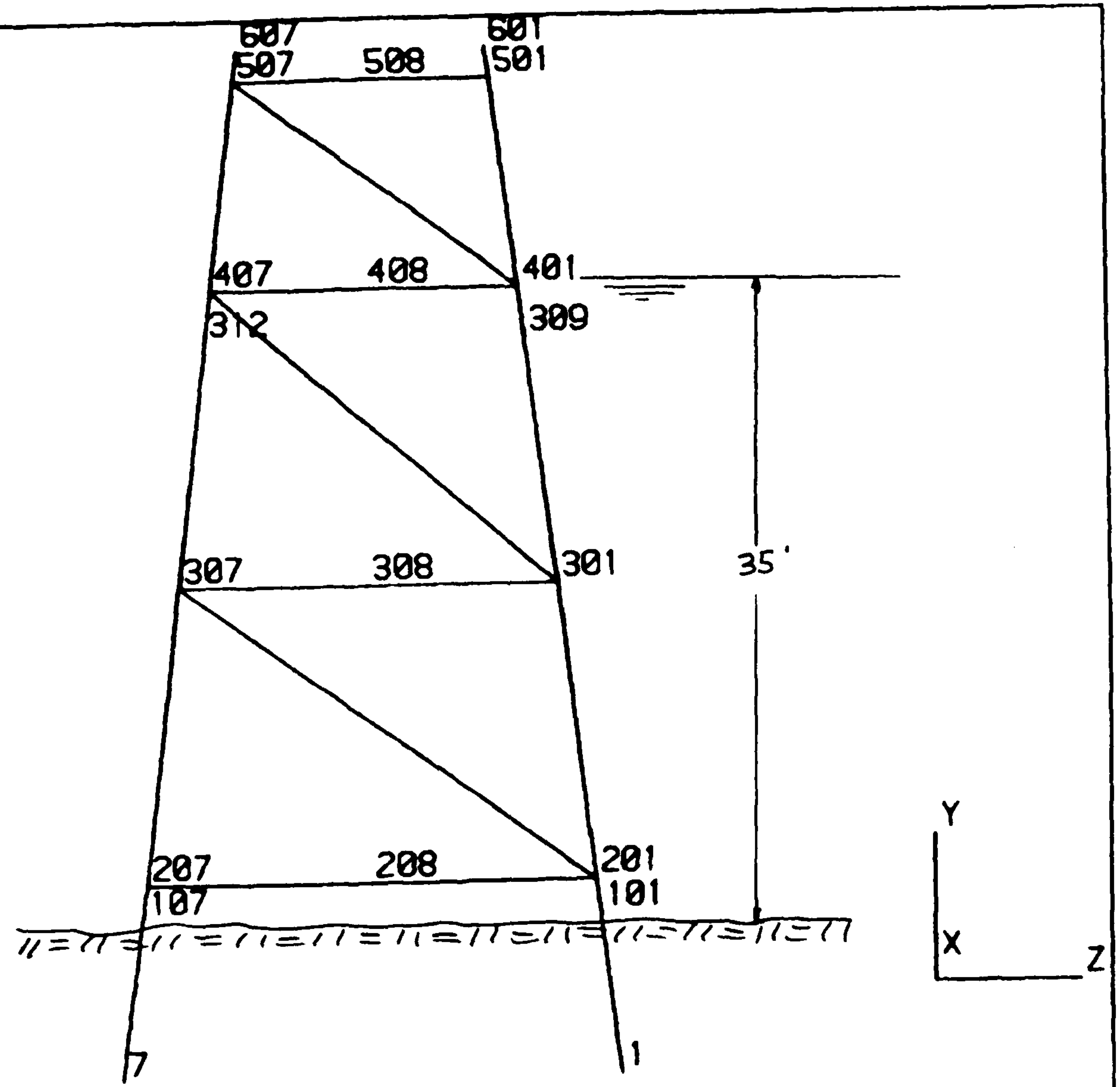



REPRODUCED AT GOVERNMENT EXPENSE

EAST FACE JOINTS
AS BUILT MODEL

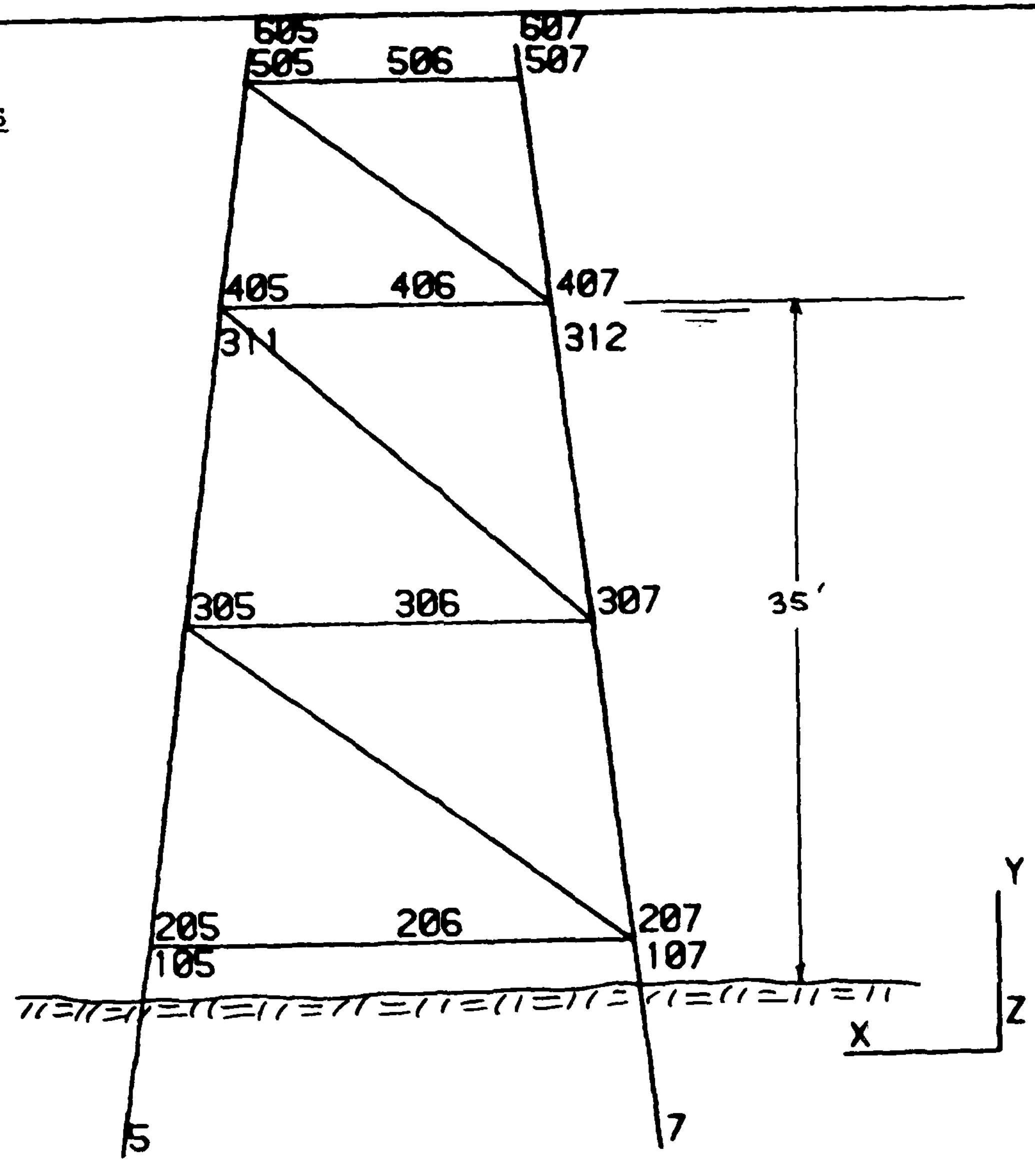


**WEST FACE JOINTS**
AS BUILT MODEL




REPRODUCED AT GOVERNMENT EXPENSE

NORTH FACE JOINTS
AS BUILT MODEL

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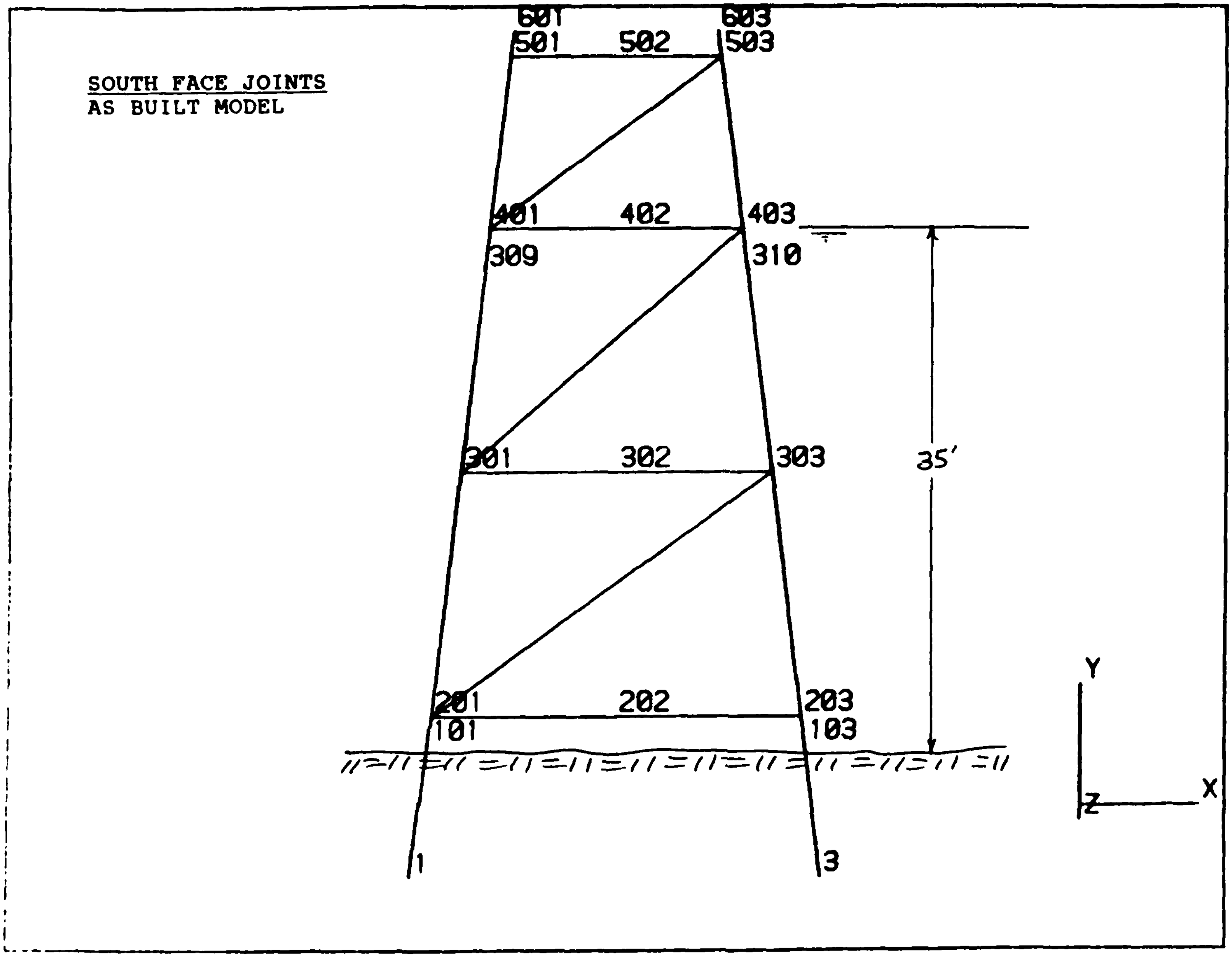
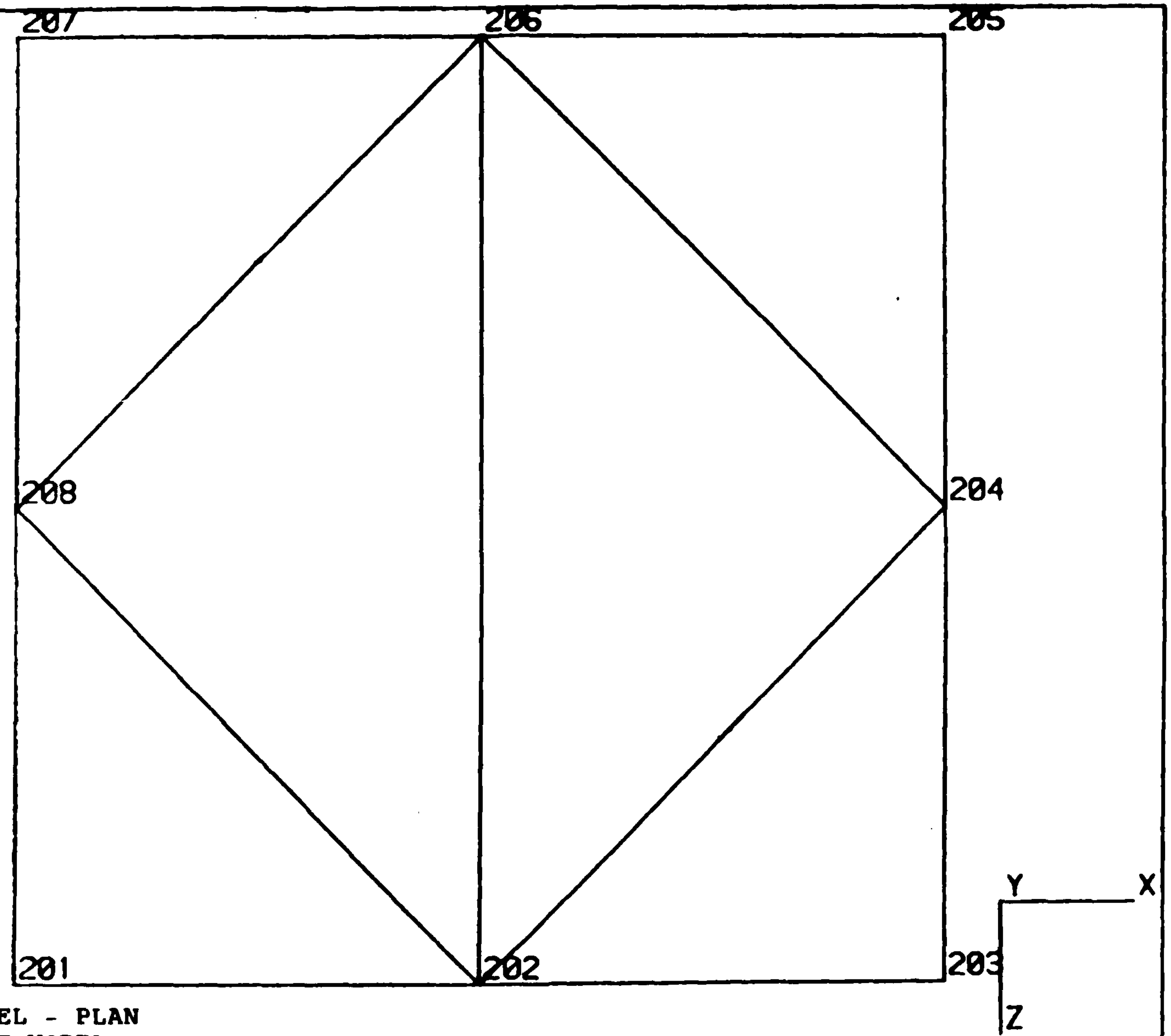
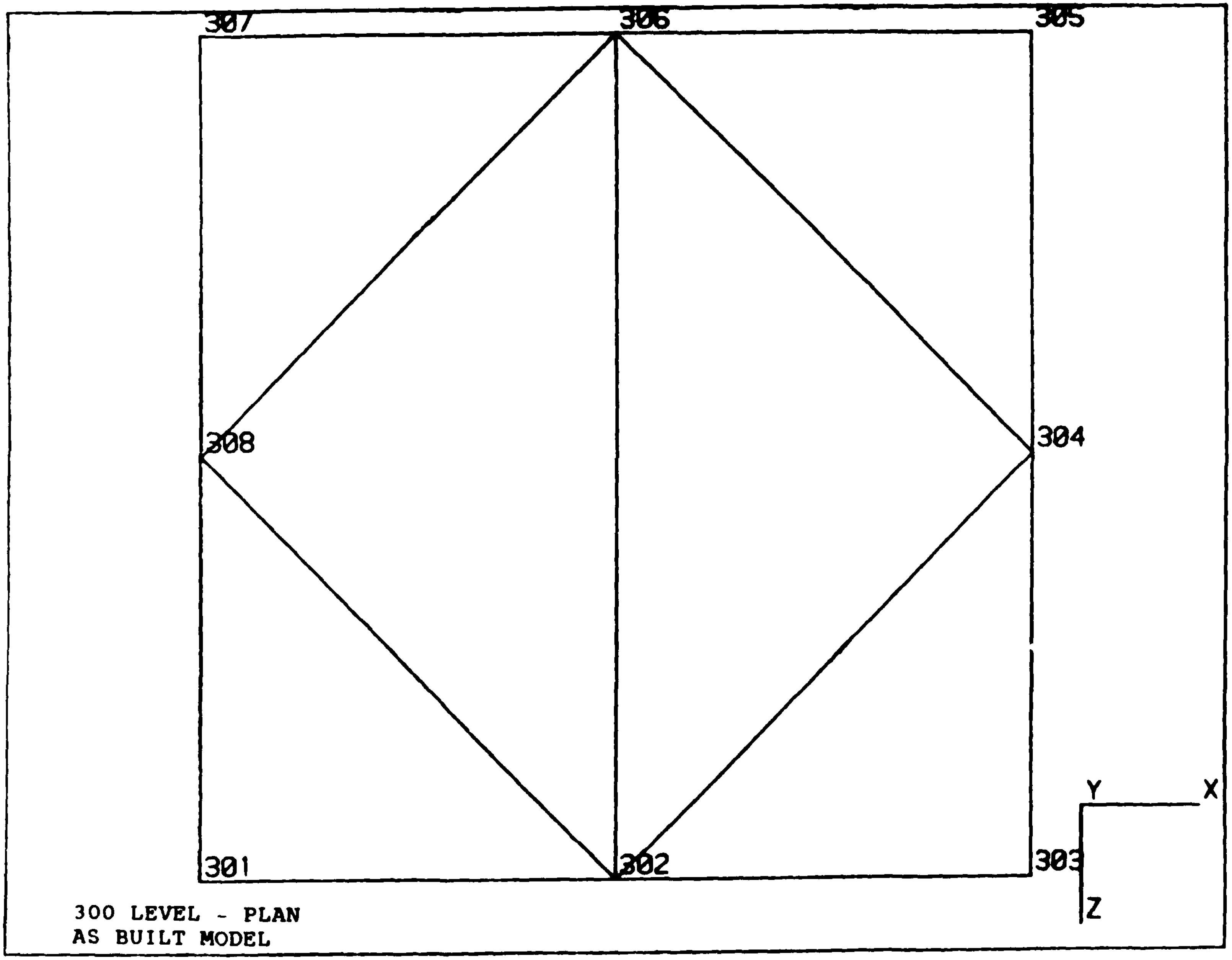



REPRODUCED AT GOVERNMENT EXPENSE




200 LEVEL - PLAN
AS BUILT MODEL

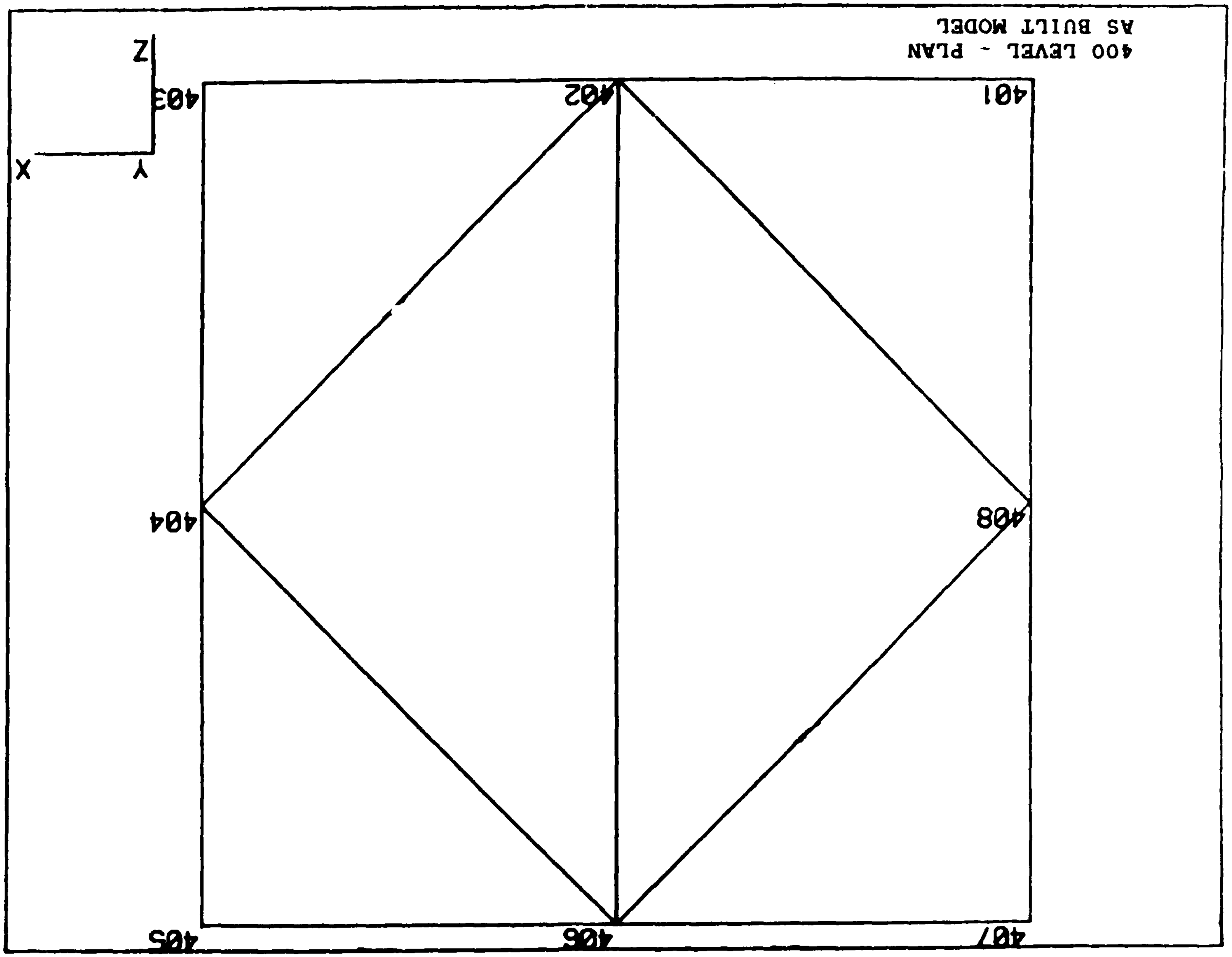
REPRODUCED AT GOVERNMENT EXPENSE

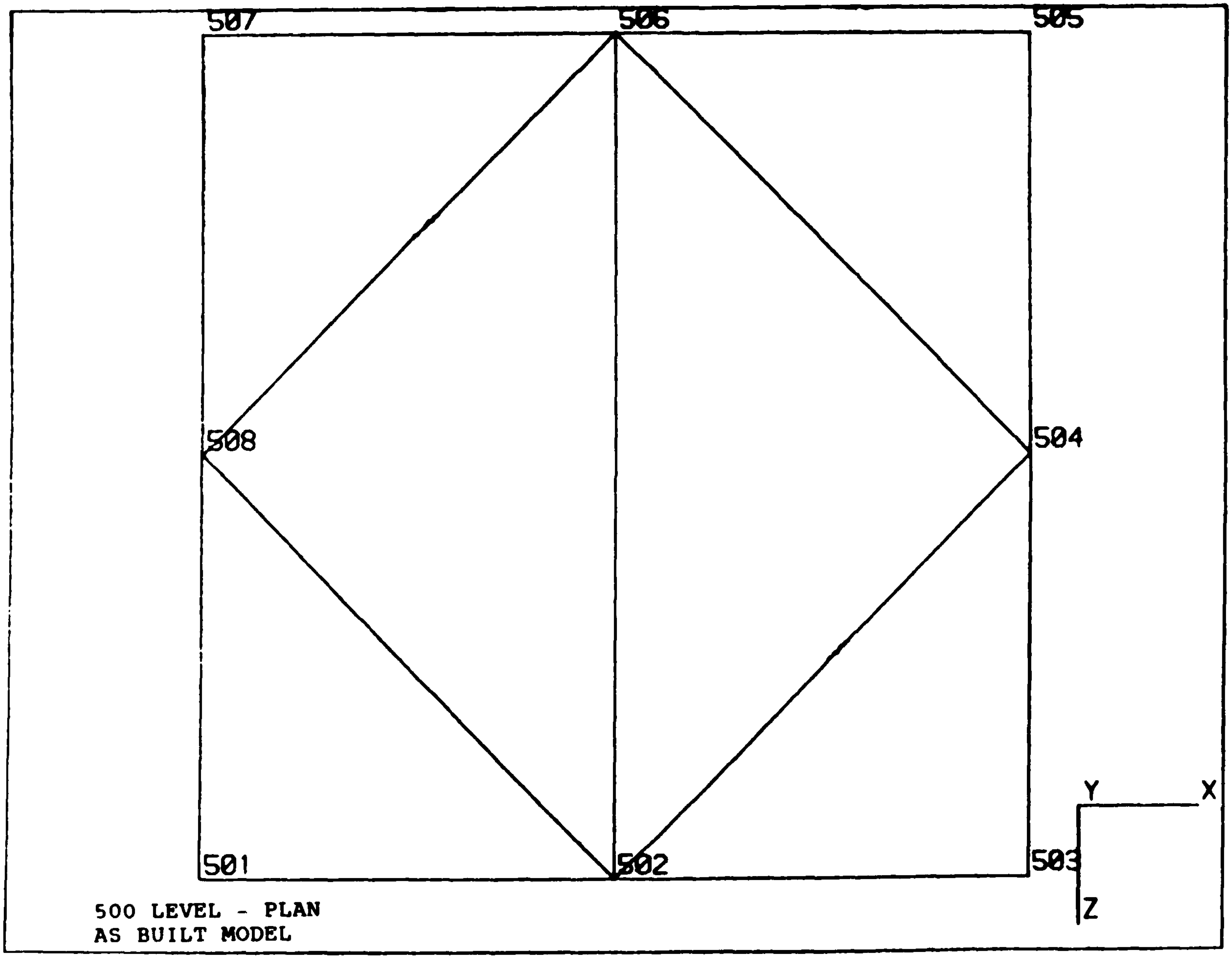


300 LEVEL - PLAN
AS BUILT MODEL

REPRODUCED AT GOVERNMENT EXPENSE

REPRODUCED AT GOVERNMENT EXPENSE





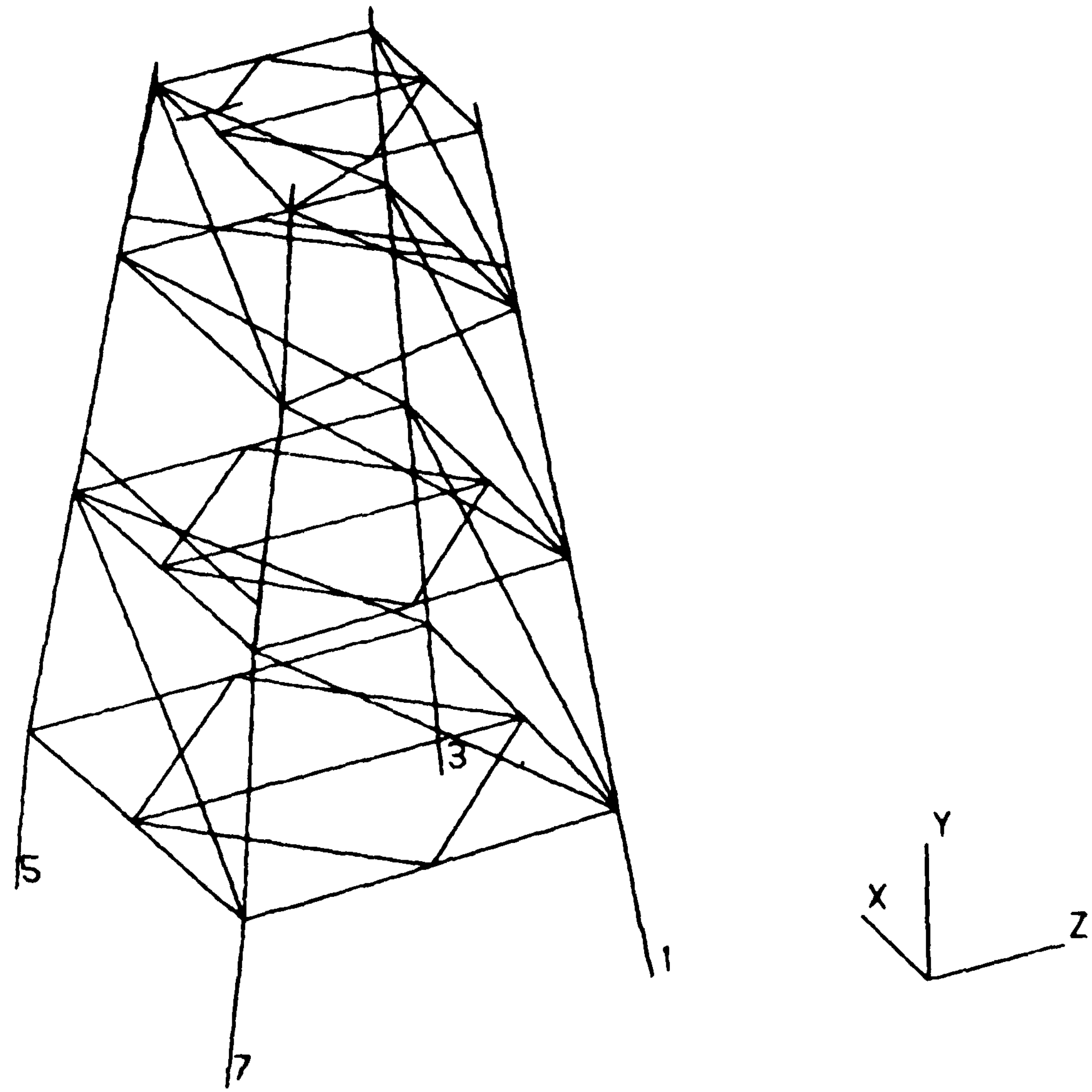

500 LEVEL - PLAN
AS BUILT MODEL

REPRODUCED AT GOVERNMENT EXPENSE

# APPENDIX C: REVISED MODEL SKETCHES AND DAMAGE MODELING

REPRODUCED AT GOVERNMENT EXPENSE

**ISOMETRIC VIEW**
REVISED MODEL




REPRODUCED AT GOVERNMENT EXPENSE

**PILE SECTIONS**

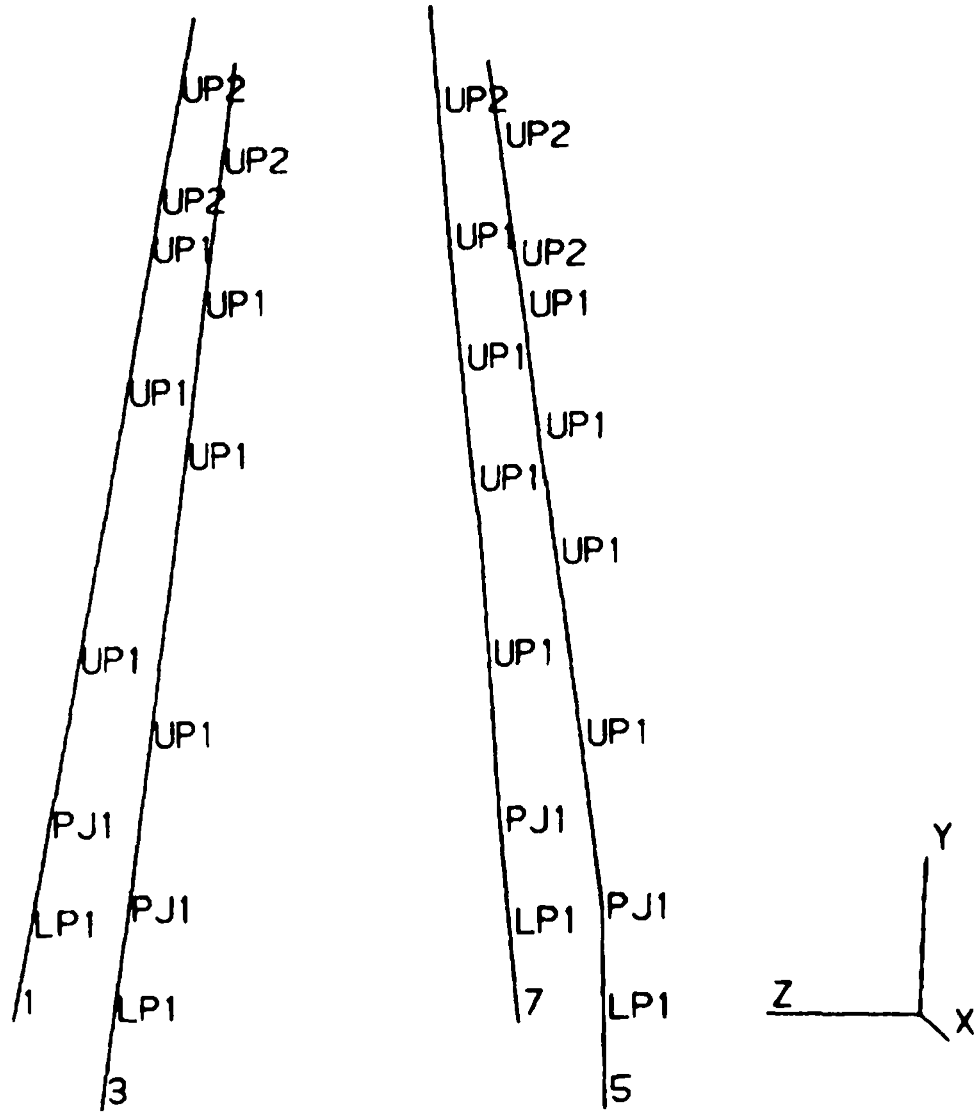
REVISED MODEL

UP2=PILE ABOVE WATER

UP1=PILE BELOW WATER

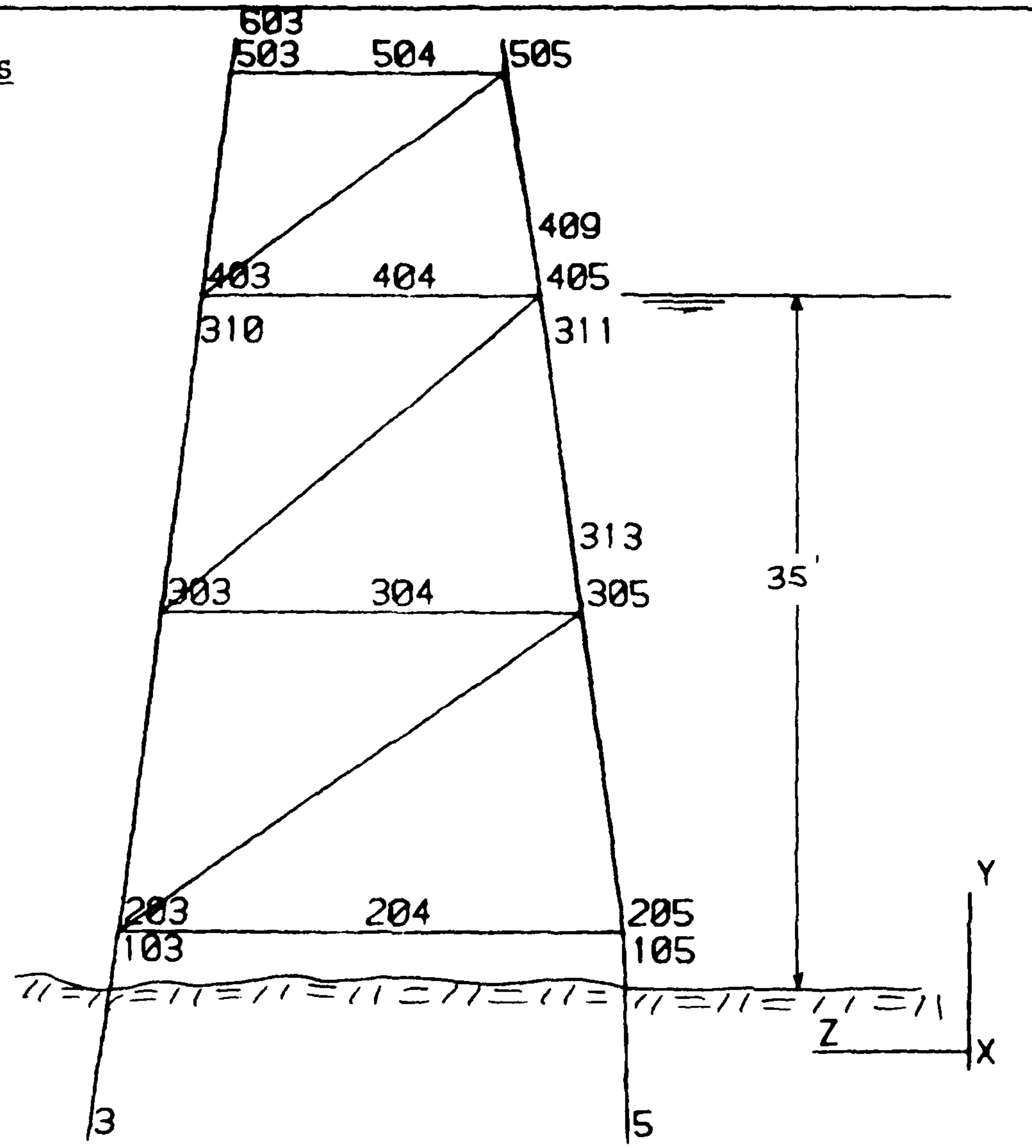
PJ1=PILE AND JACKET
    GROUTED TOGETHER

LP1=PILE IN SOIL



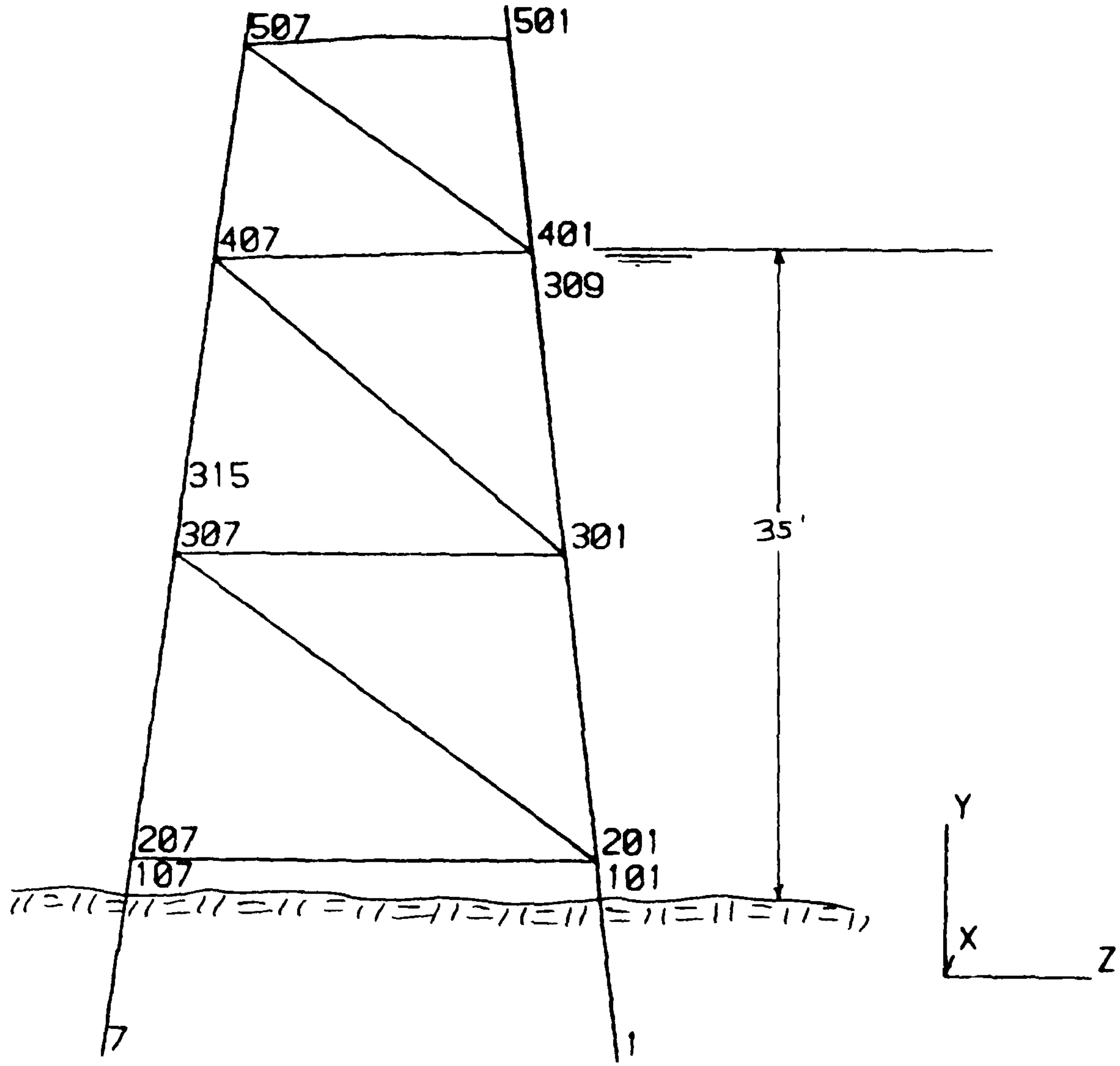

REPRODUCED AT GOVERNMENT EXPENSE

EAST FACE JOINTS
REVISED MODEL



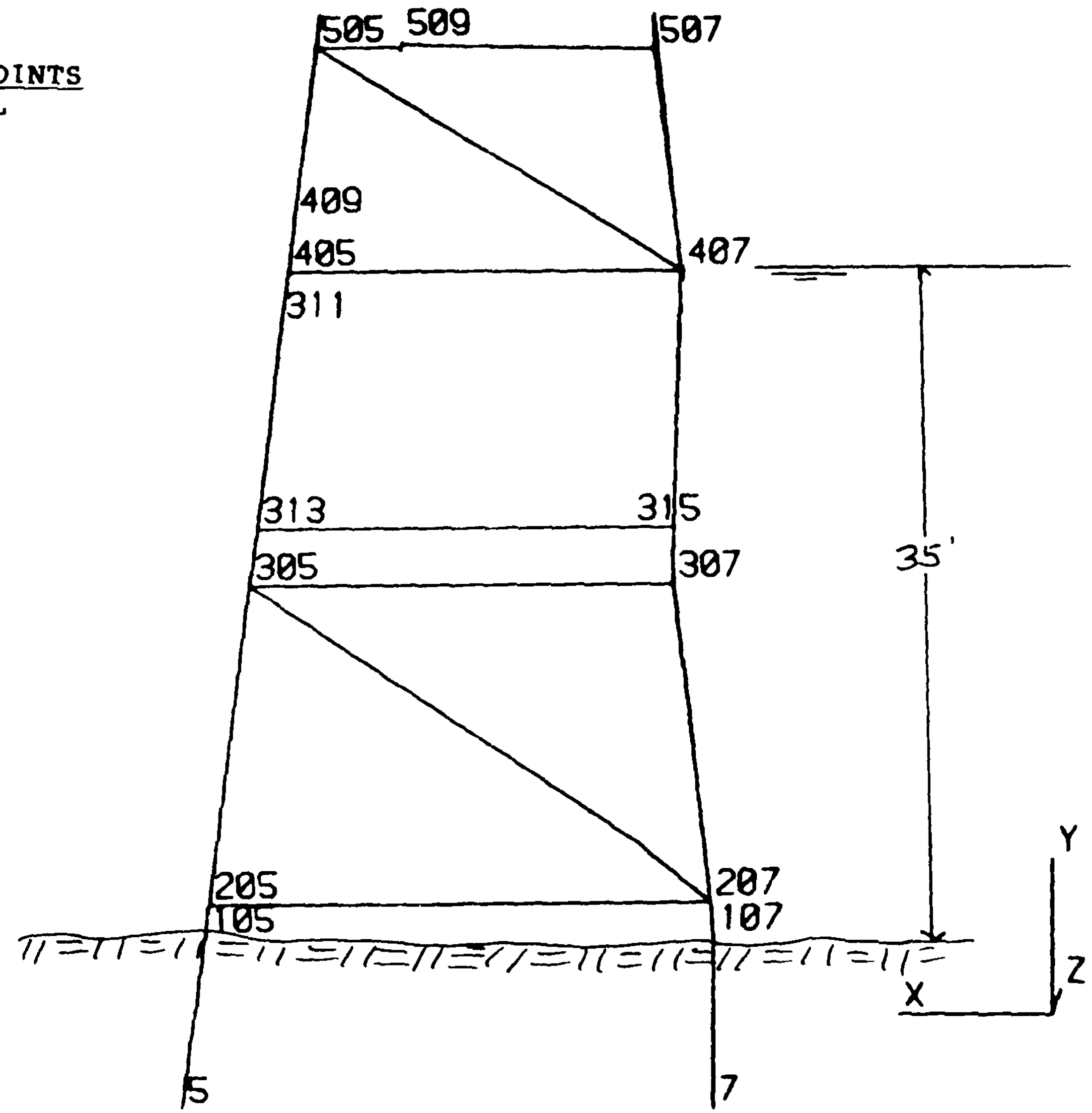

REPRODUCED AT GOVERNMENT EXPENSE

**WEST FACE JOINTS**
REVISED MODEL



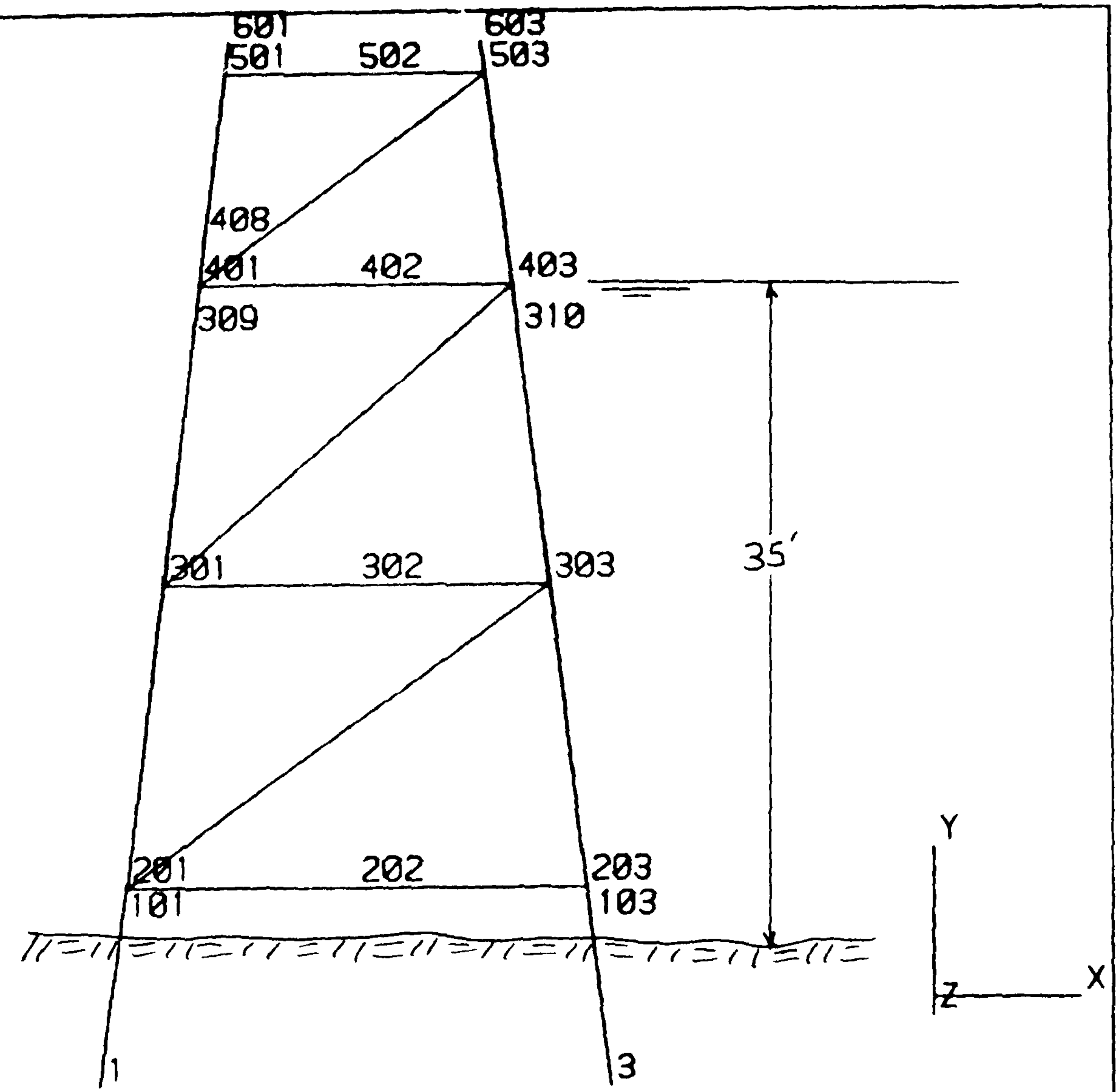

REPRODUCED AT GOVERNMENT EXPENSE

NORTH FACE JOINTS
REVISED MODEL



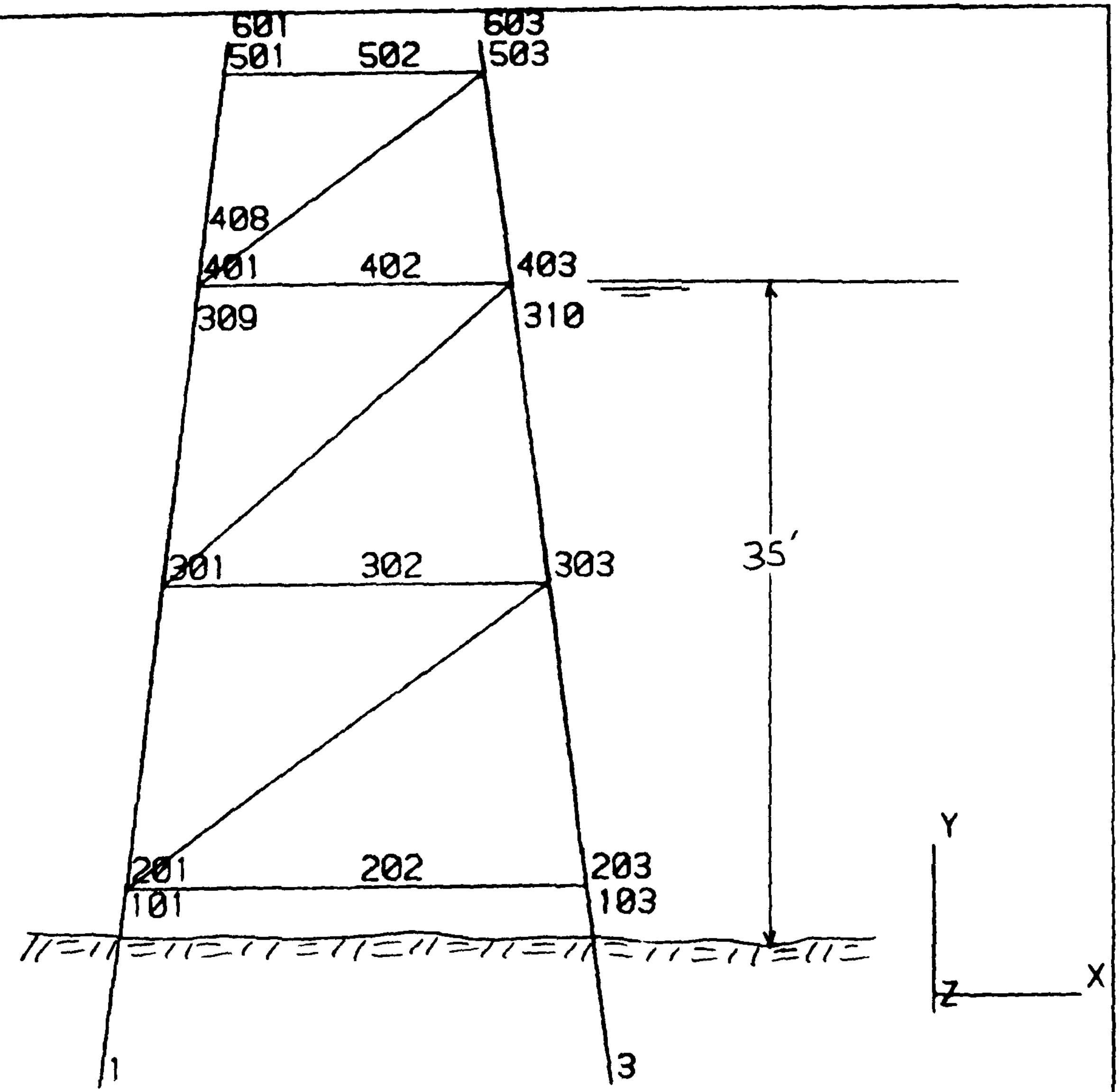

REPRODUCED AT GOVERNMENT EXPENSE

SOUTH FACE JOINTS
REVISED MODEL

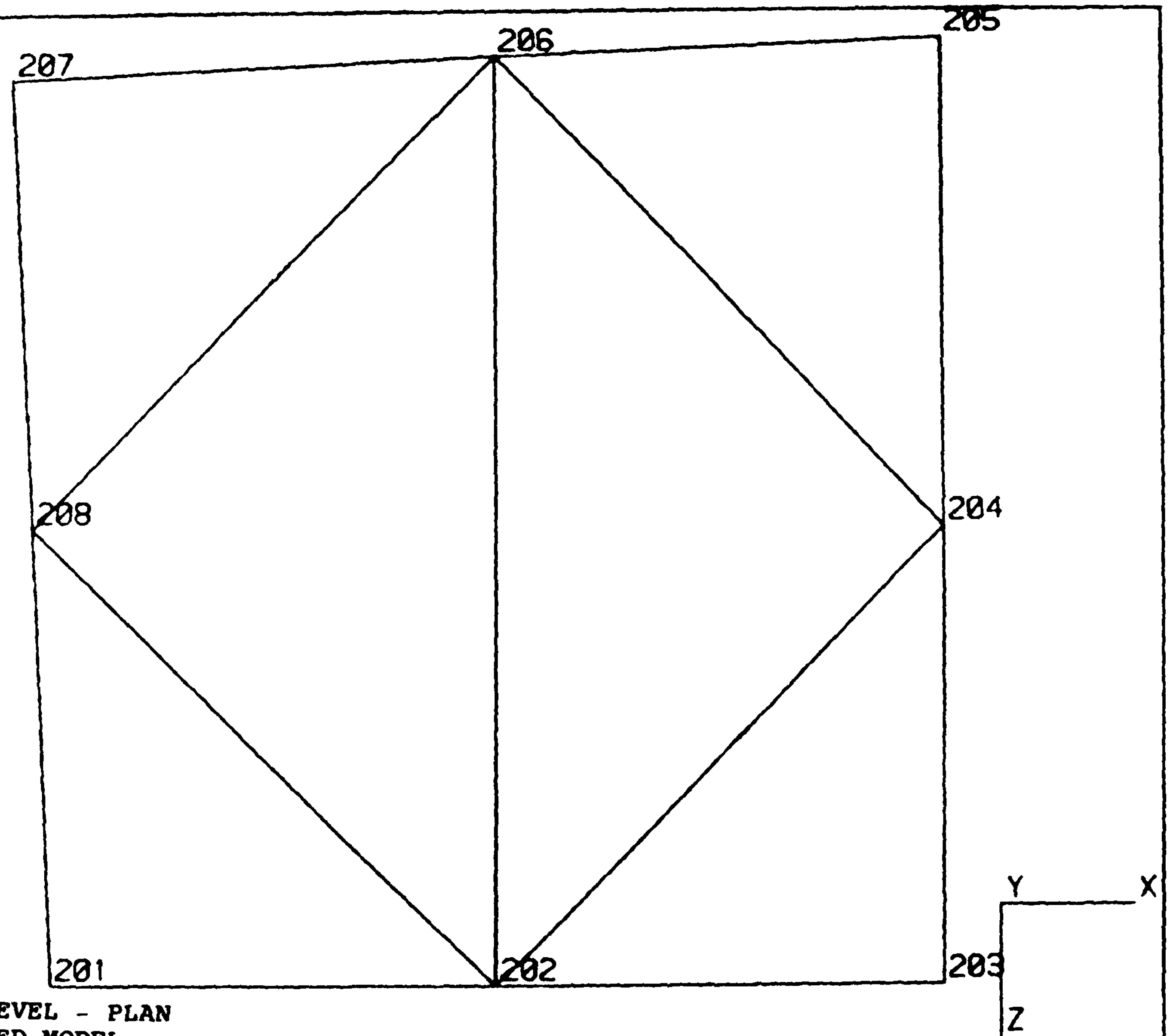



REPRODUCED AT GOVERNMENT EXPENSE

**SOUTH FACE JOINTS**
REVISED MODEL

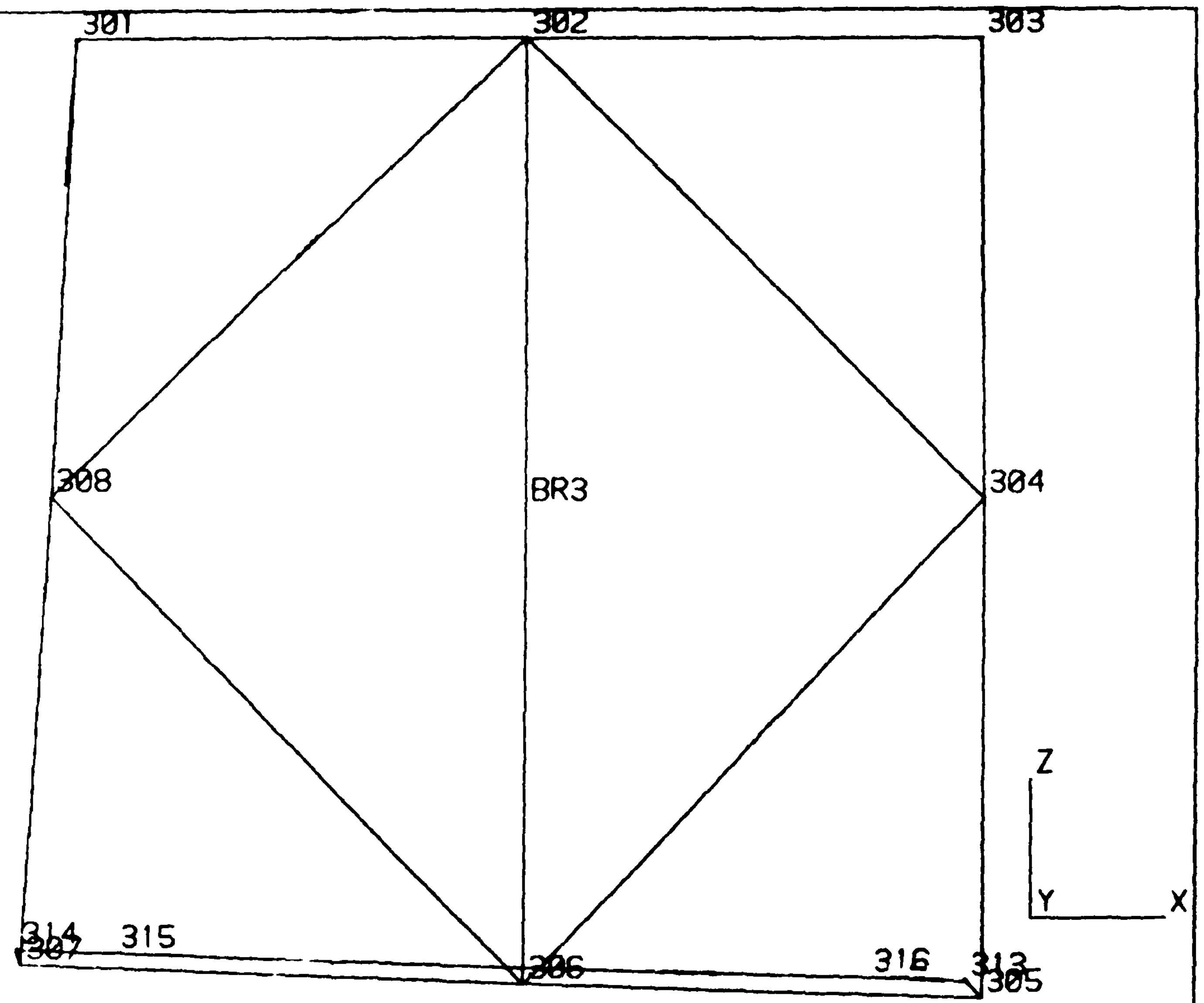



REPRODUCED AT GOVERNMENT EXPENSE



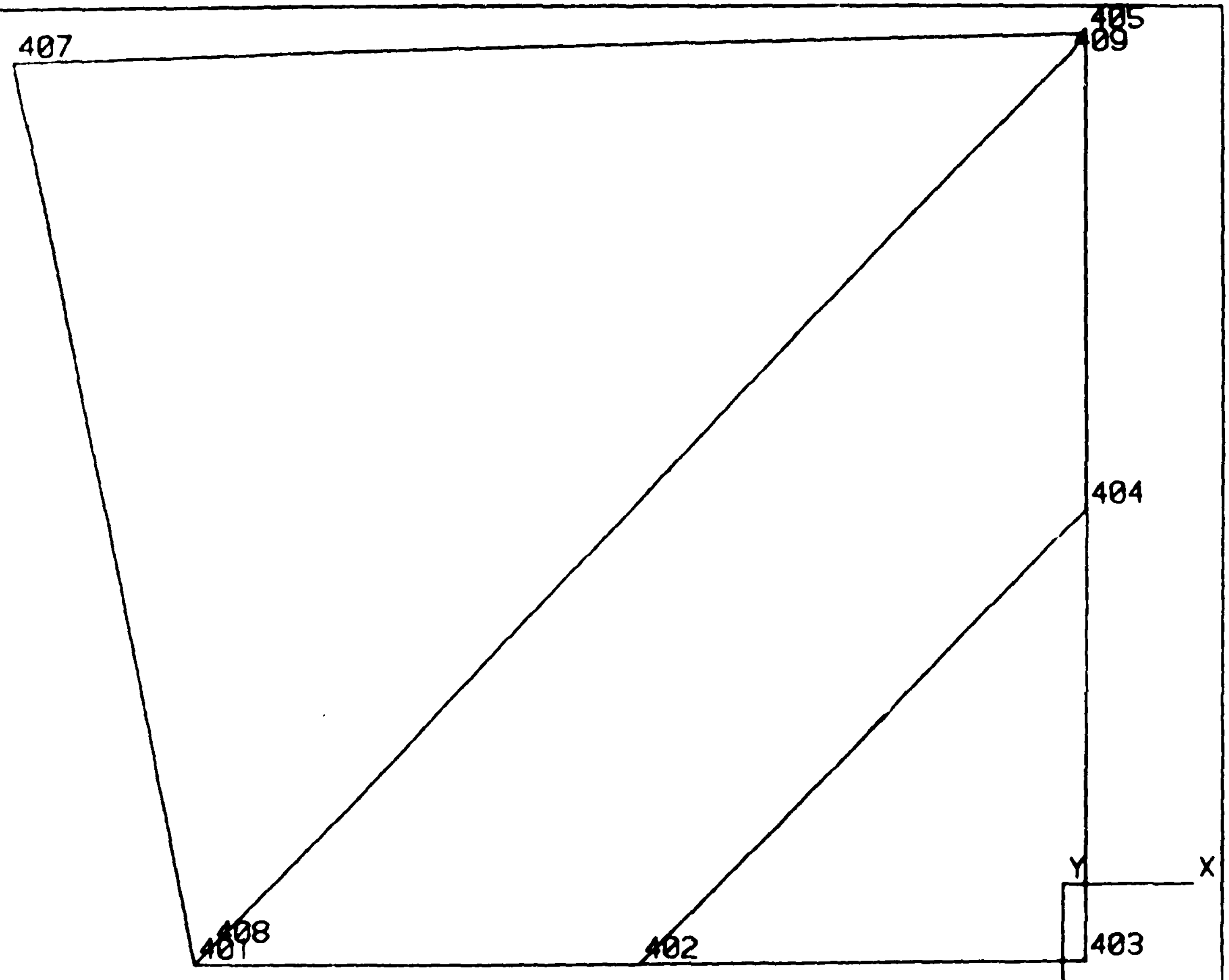

200 LEVEL - PLAN
REVISED MODEL

REPRODUCED AT GOVERNMENT EXPENSE



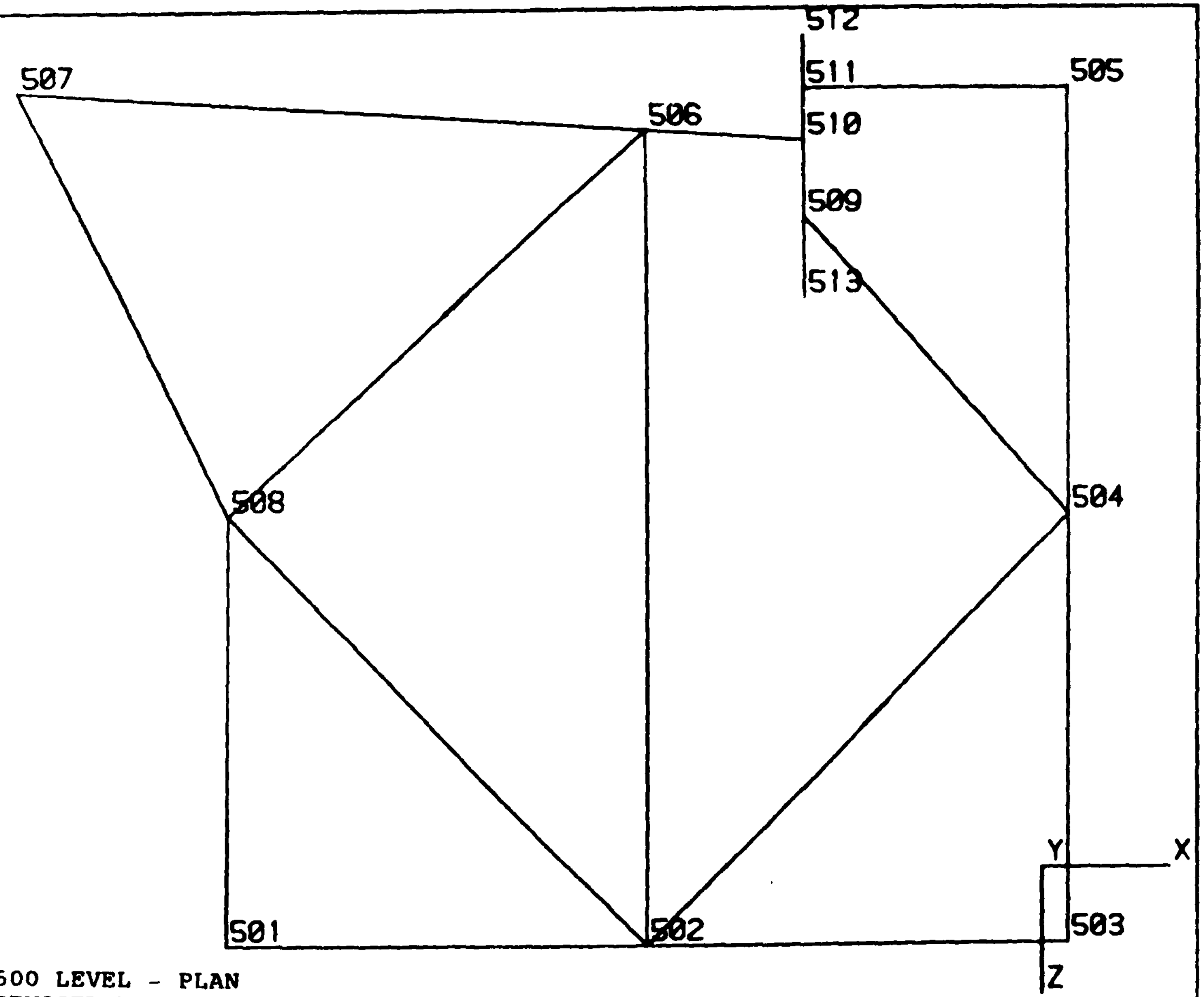

300 LEVEL - PLAN
REVISED MODEL

REPRODUCED AT GOVERNMENT EXPENSE




400 LEVEL - PLAN
REVISED MODEL

REPRODUCED AT GOVERNMENT EXPENSE




500 LEVEL - PLAN
REVISED MODEL

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION<br>Naval Facilities Engineering Command NDW<br>DISCIPLINE | PROJECT:<br>Station:<br>E S R: Contract: |
|---|---|
| Calcs made by: date: 11/28<br>Calcs ck'd by: date: | Calculations for: |

DAMAGE AND REPAIR MODELING

Member 107-207 - Grouted pile and jacket @ 207

Probable punching shear damage to jacket @ 207 assume grout is broken. (will still take compression)

- Release @ 207 for all rotations only

Member 207-307 - Jacket leg A1 @ 207

Same as 107-207

- Release @ 207 for all rotations only

Member 206-207 - Horizontal brace, north side @ 207

"Horizontal bracing cracked 'Both Sides'" @ 207
Crack shown on sketch. Assume 1/2 of weld gone

- Create node 2069 5' away from 207
- 206-207 ⇒ 206-2069
- Create new group w/ 1/2 wall thickness for 2069-207
- If unity check > 2.0 → release all fixity @ 207 for this member



GPO 888-033

REPRODUCED AT GOVERNMENT EXPENSE

| CHESAPEAKE DIVISION | PROJECT: |
|---|---|
| Naval Facilities Engineering Command NDW | Station: |
| DISCIPLINE | E S R: Contract: |
| Calcs made by: date: | Calculations for: |
| Calcs ck'd by: date: | |

Member 207-208 - Horizontal brace, west side @ 207

"Horizontal bracing cracked both sides." Not marked as cracked on plan sketch. Joint sketch unclear. Assume similar damage as 206-207 because pile has moved and rotated.

- Create node 2071 5' away from 207
- 207-208 ⇒ 2071-208
- 207-2071 is same group as 2069-207
- If unity check > 2.0 ⇒ release all fixity @ 207 for this member.

2071-208 same as 206-2069

Member 207-305 - Diagonal brace, north side @ 207

"Diagonal bracing cracked 'both sides'". @ 207. Not marked on joint sketch or plan sketch. Assume same damage as other braces @ 207 due to impact on jacket leg A-1.

- Create node 2073 5' up from 207
- 207-305 ⇒ 2073-305
- Create new group for 207-2073 w/ 1/2 wall thickness
- If unity check > 2.0 ⇒ release all fixity @ 207 for this member



GPO 885-653

REPRODUCED AT GOVERNMENT EXPENSE

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| Calcs made by: date: | Calculations for: |
| Calcs ck'd by: date: | |

Member 205 - 305 - Jacket leg B1 @ 305

· Punching shear failure to jacket @ horizontal connection - Major leg B-1 damage shown on plan sketch but not joint sketch. Assume similar damage as @ 207

· Release @ 305 for all rotations and vertical translation.

Member 207 - 307 - Jacket leg A1 @ 307

· Horiz. & Diag. bracing torn from column removing portion of jacket. Main pile exposed. Punching shear failure of jacket. Assume similar damage as @ 207

· Release @ 307 for all rotations and vertical translation.

Member 307-314 - Jacket leg A1 @ 307

Same damage as above

· Release @ 307 for all rotations and vertical translation.



GPO 885-853

REPRODUCED AT GOVERNMENT EXPENSE

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|---|---|
| Calcs made by: ______ date: ______<br>Calcs ck'd by: ______ date: ______ | Calculations for: ______ |

Member 305-313 - Jacket leg B1 @ 305

Same damage as 205-305 @ 305

- Release @ 305 for all rotations and vertical translation.

Member 305-306 - Horizontal brace, north @ 305

"Punching shear failure to jacket [FROM B-2 DESCRIPT] @ Horizontal bracing" confirmed on plan sketch but not on joint sketch. Assume damage similar to that @ 207 for 206-207

- Create node 3051, 5' away from 305
- 305-306 ⇒ 3051-306
- Create new group w/ 1/2 thickness for 305-3051
- If unity check > 2.0 ⇒ release all fixity @ 305 for this member

Member 306-307 - Horiz. brace, north @ 307

connection completely severed.

- Release @ 307 for all rotations and translations.



GPO 888-853

REPRODUCED AT GOVERNMENT EXPENSE

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| Calcs ck'd by: date: | |

Member 307-308 - Horiz. brace, west @ 307

Horizontal bracing cracked @ end connection. Joint sketch shows 16 long 1/2" wide crack. Confirmed by plan sketch. Assume 1/2 of weld is gone.

- Create node 3071. 5' away from 307
- 307-308 ⇒ 3071-308
- Create new group w/ 1/2 wall Thickness for 307-3071
- If units check > 2.0 ⇒ release all fixity @ 307 for this member.

Member 3071-308 - Horiz. brace, west @ 308

33" long 1/2" wide crack from isometric and plan sketches. This is a long large crack for an 18" member. Assume no strength left at this end. Remaining steel should quickly yield when loaded.

- Release @ 308 for all translations and rotations.

Member 301-308. Horiz. brace, west @ 301

Isometric shows no damage. Joint sketch shows none. Plan shows damage which is probably on diagonal — No action

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GPO 888-883

REPRODUCED AT GOVERNMENT EXPENSE

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| Calcs ck'd by: date: | |

Member 301-407 - diag brace, west @ 301

connection cracked" 14' long 3' wide crack in joint sketch. large crack on plan sketch. Assume 1/2 of connection is gone.

- add node 3013, 5' from 301
- 301-407 => 3013-407
- 1/2 wall thickness for 301-3013
- if unity check > 2.0 => release all fixity for member @ 301

Member 313-316-315-314 - Horiz brace, north

Replacement member - clamp and pin design. Already added in previous model

- Pinned @ both ends of 315-316 in local y + z

Member 311-313 - Jacket leg B1

Jacket buckled flat against pile for 13' section

- use reduced moment of inertia for entire section - Group JL4

Member 312-314 - Jacket leg A1

Same as 311-313 (4' section buckled)

- Reduce moment of inertia for section - Group JL4



GPO 888-883

REPRODUCED AT GOVERNMENT EXPENSE

| | |
|---|---|
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| | **E S R:** ________ **Contract:** ________ |
| **Calcs made by:** ________ **date:** ______ | **Calculations for:** ________ |
| **Calcs ck'd by:** ________ **date:** ______ | ________ |

Member 307-405 North diag brace

Removed

Member 407-401 - West horiz brace

replacement member added by cutting through jacket, inserting tube and welding to jacket. Member added previous model

Member 405-407 - North horizontal brace

Same as 407-401

Member 309-401 - Jacket leg A2 @ 401

New Brace cut through jacket and new member welded in all around with reinforcement. No strength reduction modeled

Member 312-407 - Jacket leg A1 @ 407

Same as above.

Member 311-405 - Jacket leg B1 @ 405
Same as above



GPO 888-883

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END
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