Feb 1956

United States
Salvage assoc.

H ATLANTIC
FORCES
(TE [illegible] TOW

Effects of North Atlantic
wind and wave forces on the
radar (Texas) towers

Encl. to ltr dtd 3/16/5
from H. Evans, U.S.
Salvage Association,
N.Y.

note –
WHOI involvement

UNITED STATES SALVAGE ASSOCIATION, INC.

XECUTIVE OFFICE
99 JOHN STREET
NEW YORK 38, N. Y.
CABLE ADDRESS: UNISALVAGE, N.Y.

New York
February 26th, 1956

EFFECTS OF NORTH ATLANTIC WIND AND WAVE FORCES ON THE RADAR (TEXAS) TOWERS

This report deals with wind and wave forces on the "Texas Towers", radar defense islands off the New England Coast.

No attempt has been made to explain or include the elaborate formula required for structural allowances.

While in some respects this report may appear to be incomplete, its purpose is intended only to describe the natural obstacles that had to be overcome (and understood) in the design and erection of these towers.

Prepared by:

Herbert Evans

ACKNOWLEDGMENTS

First and foremost, the United States Salvage Association, Incorporated, must acknowledge its indebtedness to the Department of the United States Navy, Bureau of Yards and Docks, for use of their Feasibility Report which was the basic guide and authority in the compilation of this text; also to:

Admiral Edward Smith, U. S. N. Hydrographer
Woods Hole Oceanographic Institute
Falmouth, Massachusetts

Dr. W. J. Pierson, Professor of Oceanography
New York University
New York, New York

Captain J. J. Albers (CEC) U. S. N.
Officer in Charge of Texas Towers
Boston, Massachusetts

Dr. P. C. Rutledge of the design firm, Moran, Proctor, Mueser and Rutledge
New York, New York

CONTENTS

PAGE

PART I

WAVE EFFECT ON RADAR TOWERS AND A GENERAL DESCRIPTION OF OCEAN WAVES. 1

PART II

ANALYSIS OF MAXIMUM STORM WINDS AND WAVES. 4

PART III

TIDES AND TIDAL CURRENTS. 7

PART IV

SAFE CONSTRUCTION PERIOD WAVE HEIGHT DESIGN STRESSES. 8

PART V

WAVE HEIGHT ABOVE MEAN SEA LEVEL. 12

PART VI

FATIGUE, EMBRITTLEMENT AND VIBRATIONS, ABRASION FROM WATER-BORNE SAND. 13

PART VII

DRAWINGS AND DIAGRAMS

WAVE EFFECT ON RADAR TOWERS

PART I

Wave action was one of the major problems to overcome in designing the Radar Towers for permanent anchoring off the Atlantic Coast. In deciding the tower's position, consideration was given to wave refraction and diffusion (due to the shoal's shape) to minimize wave effect.

In order to understand how calculations for wave effect were made, some idea of the ocean wave's characteristics will be required.

The most common type of wave in the open sea is the wave caused by the wind. Wind does not blow at a constant velocity, but always in irregular gusts, and these gusts subject the ocean surface to irregular unequal pressures which deform it from a level surface into one of troughs and crests. The size of ocean waves depend upon the strength of wind, its' duration, and the extent of open waters over which it blows.

From observation it is found that the length of waves are increased when the length of fetch, or length of the water to windward, is increased. The energy of a wave, and consequently it's destructive force, depends upon it's length, height and velocity.

The length of a wave is the horizontal distance from trough to trough, or from crest to crest.

The height of a wave is the vertical distance measured from the bottom of the trough to the top of the crest.

The period of a wave is the time interval in seconds between the passage of two successive crests past a fixed point.

The velocity of a wave is the rate at which it's crests move forward, or the velocity equals the length divided by the period. By approximation, the velocity in knots nearly equals three times the period in seconds.

The maximum length of a wave in the North Atlantic appears to be about 1,600 feet which corresponds to a period of about 16 seconds. Longer waves may have been reported for the North Atlantic, but they are extremely unusual and the observations are questionable.

Average size of Atlantic Waves - Waves from 500 to 600 feet in length are sometimes encountered in the North Atlantic, but generally they are from 150 to 300 feet with periods from 6 to 8 seconds.

Extremely high waves are occasionally reported for the North Atlantic, these range up to 60 feet in height. The very high waves are usually little waves on top of big waves, and as such they do not involve much water in the peak region. In some of these "very high waves", much of the energy is spent in up and down motion rather than forward motion. Thus, the energy available in these oversized waves which can be spent in a horizontal direction may not necessarily be the same type of function of wave height as for low or medium waves.

DISTURBANCE BENEATH SURFACE

The disturbance set up by the wave motion extends for some distance below the surface, but the size of the orbits, through which the water particles move, decreases rapidly with increase in depth. At a depth equal to one wave length, it is less than a five hundredth part of what it was at the surface, so that water at that depth may be considered undisturbed and any motion associated with the largest ocean waves is inappreciable at even modest depths.

WAVE EFFECT IN SHOAL WATER

Waves from deep water are modified as they get into shoal water. When the depth is reduced to less than one-half the wave length the orbit of the particles

COMMENCE TO BECOME FLAT. THE PERIOD REMAINS UNCHANGED, BUT LENGTH AND SPEED ARE ~~IN~~deCREASED, THE WAVE BECOMES HIGHER AND SHORTER, THE CREST ARCHES FORWARD AND FINDING ITSELF UNSUPPORTED BY SUFFICIENT WATER ON THE FRONT, DASHES DOWNWARD, PRODUCING A WAVE BROKEN INTO SURF.

SWELL

AS WAVES MOVE BEYOND THE WIND-SWEPT REGION THEY GRADUALLY LESSEN IN HEIGHT AND GIVE RISE TO GENTLE UNDULATION KNOWN AS SWELL, OR GROUND SWELL. THE TERM SWELL IS ALSO USED TO DENOTE THE GRADUAL DYING DOWN OF WAVES THAT THE WINDS HAD PREVIOUSLY SET UP.

A STORM WAVE MAY BREAK AS A SPILLING BREAKER SEVERAL TIMES, OR EVEN CONTINUOUSLY, AND THE CREST ANGLE WILL BE ABOUT 120°. NO VERTICAL FRONT WILL APPEAR. IF A SWELL BREAKS ON A SHOAL, IT WILL LOSE MUCH ENERGY AND NOT BREAK AGAIN AS LONG AS THE WATER DEPTH REMAINS CONSTANT. THUS, ON THE INSIDE OF A SHOAL, ONLY SPILLING BREAKERS WOULD BE GENERALLY EXPECTED.

NOTE: NO ATTEMPT HAS BEEN MADE IN THIS REPORT TO DESCRIBE OCEAN WAVES CAUSED BY OTHER FORCES OF NATURE, I.E., SUBMARINE, EARTHQUAKE, OR SUBMARINE VOLCANIC EXPLOSION.

PART II

MAXIMUM WINDS AND WAVES

A study of weather maps for the last twenty years has yielded the results shown in Table "I". The wave predictions in this table are based on a study made at New York University for the Bureau of Aeronautics, United States Navy, the results of which are contained in "Practical Methods for Observing and Forecasting Ocean Waves", July 1953.

TABLE I

ANALYSIS OF MAXIMUM STORM WINDS AND WAVES

Analysis by Woods Hole Oceanographic Institution using Weather Bureau maps.

			Winds				
Type	Date	Dir.	Ave. Vel. Mph.	Duration Hrs.	Fetch Mi.	Max. Vel. Mph.	Wave Height* Ave. of 10%-Highest Ft.
Hurricane	Sept. 21, '38	SSE	90	8	400	120	50
Hurricane	Oct. 4, '51	S	45	30	500	70	43
Storm	Dec. 3-4, '37	NE	55	30	600	65	48
Storm	Nov. 29-30, '45	E	70	30	600	75-90	66
Storm	Sept. 22, '53	S	40	24	600	50	32
Storm	Nov. 7, '53	E	60	30	600	70	48

* NOTE: During these maximum storms 80% of all waves will be less than 0.7 times these heights, but single maximum waves may be 1.5 times heights listed.

It will be noted in Table "I" that the maximum wind occurred during a huricane at a velocity of 120 miles per hour and that the computed average height of the 10% highest waves is 66 feet during an easterly storm. The computed wave heights are based on

A STATISTICAL PROCEDURE OF ANALYSIS APPLIED TO WAVE SPECTRA CONFORMING CLOSELY TO ACTUAL SEA WAVES. THIS THEORETICAL METHOD HAS BEEN CHECKED FOR SEA CONDITIONS WHERE THE MAXIMUM HEIGHT OF WAVES IS APPROXIMATELY TWENTY (20) FEET. NO CHECKS ARE YET AVAILABLE FOR HIGHER SEA CONDITIONS. ACCORDING TO THE STATISTICAL THEORY, MOST OF THE WAVES IN A STORM WILL BE CONSIDERABLY LOWER IN HEIGHT THAN THE AVERAGE OF THE 10 PER CENT HIGHEST WAVES; BUT, THEORETICALLY, ONE WAVE IN ONE THOUSAND DURING MAXIMUM STORM WILL HAVE A HEIGHT 1.5 TIMES THE HEIGHT OF THE AVERAGE OF THE 10 PER CENT HIGHEST AND ONE WAVE IN TWENTY THOUSAND MAY BE EVEN HIGHER. IN THIS CONNECTION, IT MAY BE WELL TO QUOTE COMMENTS FROM THE NEW YORK UNIVERSITY REPORT AS FOLLOWS:

> "EXCEPTIONALLY HIGH WAVES REPORTED AS RARE OCCURRENCES HAVE BEEN ACTUALLY OBSERVED. THEY ARE OFTEN REPORTED BY SEA-GOING MEN AND THERE HAS BEEN A LOT OF SPECULATION AS TO HOW AND WHY THEY FORM. THESE HIGH WAVES FORM BECAUSE THEY ARE A BASIC PROPERTY OF THE RANDOMNESS OF THE WAVES. IN HEAVY SEAS, OR FULLY DEVELOPED SEAS, THESE OUTSIZE WAVES ARE VERY UNSTABLE. THEY MAY BE BREAKING AT THE CRESTS AND PRODUCE A WALL OF PLUNGING WHITE WATER OUT IN THE MIDDLE OF THE OPEN OCEAN. THESE OUTSIZE WAVES THEN ARE DESTROYED BY THEIR VERY HEIGHT. THUS, IN A HEAVY SEA, THEY ARE RARE."

THE SCIENTISTS OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION AGREE THAT THE OUTSIZE OR "GIGANTIC" WAVES DO OCCUR AND THERE ARE NUMEROUS RECORDS IN MARITIME REPORTS AND HISTORY OF SUCH WAVES BEING OBSERVED. HOWEVER, THERE IS SOME LIMITING HEIGHT BEYOND WHICH THE OUTSIZE OR GIGANTIC WAVES WILL NOT OCCUR. THEY DO NOT KNOW WHAT THIS HEIGHT IS, BUT BELIEVE THAT IN THE NORTH ATLANTIC IT IS IN THE GENERAL ORDER OF 80 TO 90 FEET. WHILE SUCH WAVES ARE ADMITTEDLY UNSTABLE, SELF-LIMITING AND OF RARE OCCURRENCE, THEIR EXISTENCE CANNOT BE IGNORED AND CONSIDERATION MUST BE GIVEN TO THE EFFECTS OF SUCH A POSSIBLE GIGANTIC WAVE ON A STRUCTURE FIXED TO THE SEA BOTTOM.

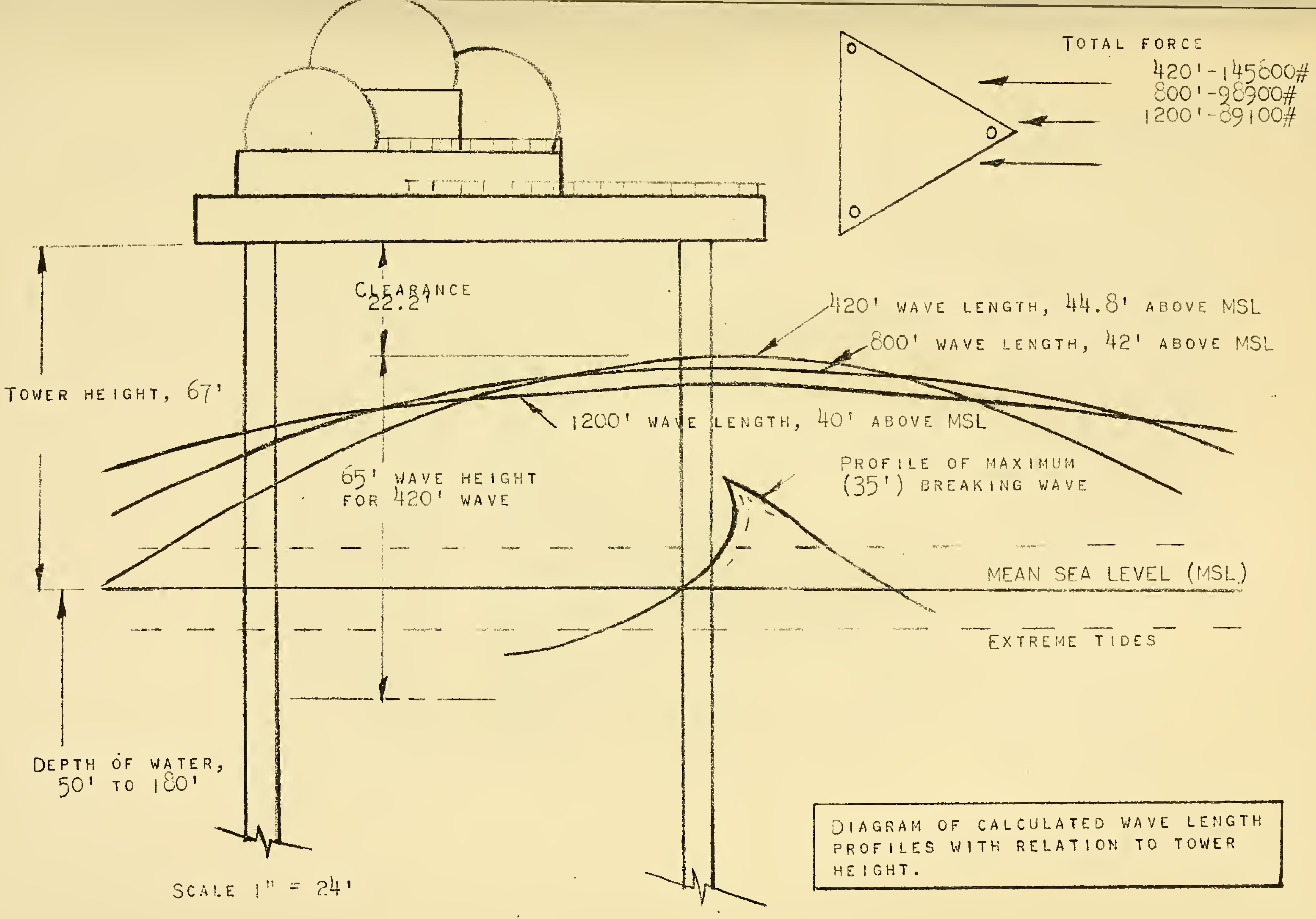


DIAGRAM OF CALCULATED WAVE LENGTH PROFILES WITH RELATION TO TOWER HEIGHT.

In open ocean, waves take the form of sea or swells. The following is a brief summary of the characteristics of seas and swells taken from a New York University Report:

> "In a sea, the waves are irregular, chaotic, short-crested, mountainous and unpredictable. High waves follow low waves in a completely mixed up way. The crests are only two or three times as long as the distance between crests...individual crests can appear to be traveling in different directions varying by as much as 20 or 30 degrees from the dominant direction. There are waves on top of waves, and crests with depressions in the top... the pattern of the sea never repeats itself and never duplicates itself. No two aerial photographs or wave records of a sea will ever be exactly alike. The pattern changes rapidly with time. The high waves die down as they travel along and soon disappear. New waves, which were once very low, form and build up to take their places. Individual wave crests can disappear completely in their tracks as they travel a distance as short as 500 feet.
>
> "In a swell, the waves are more regular, longer crested and more predictable. High waves (compared with the average) follow high waves and low waves follow low waves. When the waves are high, five or six waves of nearly the same height will pass in a row. When the waves are low, they can remain low for maybe as much as a minute and a half. If the waves are increasing in height, the next wave will be higher. If the waves are decreasing in height, the next wave will probably be lower. A guess about the height of the next two or three waves to pass on the basis of whether the wave which has passed is high or low and on the basis of whether the heights are increasing or decreasing will be right very often. A swell is predictable in a short range sense. The crests are much longer -- as much as six or seven times the distance between the crests. The pattern is still as basically unpredictable over longer time intervals as that of the sea."

PART III

TIDES AND TIDAL CURRENTS

The Woods Hole Oceanographic Institution has estimated that the maximum astronomical tides at George's Bank and Nantucket Shoals will be in the order of 2 feet above and below main sea level. This estimate has been confirmed exactly by tide cycle measurements made from the fixed platform of the drill barge during boring operations at these locations. It is possible that the astronomical tide may be somewhat greater at Cashes Ledge and somewhat less at Brown's Bank and the location off New York. The charts of Georges Bank and Nantucket Shoals show tidal currents up to velocities of 5 knots per hour varying in all directions with the stage of the tide. Observations during the drilling operations confirmed these tidal currents which maintained almost constant velocity although shifting in direction over the tidal cycle. Both the charts and observations during the drilling operations show heavy tidal rips over or near the shallowest portions of the shoal areas. Further, the Woods Hole geologists who investigated the bottom conditions in these areas by skin diving, report that the five to ten feet of water immediately above sea bottom is full of swirling sand "resembling a driving snow storm". This swirling sand is moved and held in suspension by the tidal currents. The Woods Hole Oceanographic Institution has estimated that meteorological tides may amount to as much as 6 feet and that they are likely to coincide with severe storms.

PART IV

SAFE CONSTRUCTION PERIOD

On-site construction operations can be carried out safely at the five proposed locations only during the period between May 1 and August 10 of any year. The Woods Hole Oceanographic Institute has reported that strong easterly and northeasterly storm occur and can be anticipated during the winter and spring months up to about the end of April and that August 10 is the earliest date recorded for the passage of hurricanes off the New England coast. During the period from May 1 to August 10, not more than four or five days of dead calm weather normally occur. At all other times the waves vary from a minimum of approximately 4 feet to a maximum of approximately 15 feet. A study of the weather records between May 1 and August 10, including 1200 observations of wind velocity, show that in only 10 cases out of 1200 was the wind velocity greater than 28 miles per hour and in only one case was the wind velocity greater than 40 miles per hour. A wind velocity of 28 miles per hour could produce waves the highest of which would be approximately 15 feet. The one case of a wind velocity of over 40 miles per hour could have produced a few waves as high as 25 feet. Thus, over the period of about 15 years study, there were 10 occasions when maximum heights of waves could have been about 15 feet and one case where maximum height of wave could have been 25 feet. Under these conditions it is not feasible to use any scheme which requires on-site construction procedures from floating equipment. Such equipment can not operate safely and successfully in waves over 4 feet in height. For design of construction procedures not using floating equipment, wave heights of 15 feet and wind velocity of 50 miles per hour seem to be safe for all except extreme and unusual conditions.

WAVE HEIGHT AND CONDITION AND DESIGN STRESSES

The possibilities of protection of the structures against maximum wave forces by choice of location has been reviewed with the Woods Hole Oceanographic

Institution. Cashes Ledge is protected by Brown's Bank to the northeast and east and George's Bank to the south, but has no protection against easterly storms. Protection against the maximum sea waves of southeasterly and easterly storms can be obtained at George's Bank and Nantucket Shoals by locating the structures on the lee side of shoal areas for such storms. No protection by shoal areas is available at Brown's Bank and at the location off New York. After considerable study, it was decided that the probability of 60 foot waves occurring several times during a period of twenty years at any of the locations definitely exists. On the basis of twenty-year weather records, such waves are associated with northeasterly or easterly storms, rather than with hurricanes and the wind velocities associated with such waves are those of the storms. Such waves may also be associated with regenerated swells from distant storms. Under hurricane conditions with high wind velocities, it is not probable that waves over 40 feet will occur. It is, however, definitely possible under these high wind conditions, that the waves will be unstable and will be breaking due to wind forces and independently of bottom drag conditions. On the basis of these considerations, the design criteria and allowable stresses shown in Table II have been developed. The values in this table have been concurred in by the scientists of the Woods Hole Oceanographic Institution. In connection with these values, design procedures have used the minimum wave length for stable waves of each height investigated. Thus, maximum forces have been used for the several wave heights. Under actual sea conditions, it is probable that most of the waves of these design heights will have wave lengths definitely larger than seven times the wave height. Thus, an additional margin of safety in terms of wave force has been used.

TABLE II

DESIGN CRITERIA AND ALLOWABLE STRESSES

Case	Wind Velocity MPH	Wave Height Ft.	Wave Condition	Allowable Design Stresses
1	70	60	Non-Breaking	Am. Inst. of Steel Constr Code Values
2	125	40	Non-Breaking	AISC values + 33% but not over 20,000 psi.
3	125	35	Breaking	AISC values + 50% but not over 25,000 psi.
4 *	50	15	Non-Breaking	AISC values + 50% but not over 25,000 psi.

* NOTE: Case 4 is design condition for towing and on-site construction operations, including design of auxiliary legs. The inflated domes will not be installed during this stage of construction.

It is believed that the values for design, wind, wave height and allowable design stress listed in Table II should not be reduced. A large and unresolved uncertainty remains concerning the maximum height of wave that may strike the platform supports during its useful life. While the maximum possible height is uncertain, there seems to be a definite probability that one such wave may strike the platform supports within a period of twenty years. The design has proceded on the basis that the occurrence of one such wave may cause stresses in the structural elements of the platform supports into the plastic range of stress for the structural materials. However, if the safety of the platform and the personnel on it will not be endangered and it is believed that repairs or replacements of overstressed elements can be made if such a wave occurs. Further, it has not been possible to resolve existing uncertainties concerning possible regeneration and focusing of swells coming from any possible direction. Therefore, it is believed that some margin must be provided for such swell conditions. Thus, it is believed that the design criteria values set forth in Table II are safe and reasonable, but that they should not be reduced.

ELEVATION OF BOTTOM OF PLATFORM

The maximum intensity of wave force occurs close to the maximum elevation of the wave crest. If these large intensities of wave force should be applied to large areas such as the areas of the platforms themselves, extremely large total forces would result. Therefor, safety and integrity of the platforms requires that the platforms themselves always be definitely above the crests of any waves that may pass them. This conclusion is confirmed by experience with offshore oil well drilling platforms in the Gulf of Mexico where major failures and complete loss of the platforms has been reported in two instances as the result of wave crests striking the platforms themselves. On this basis the evaluations of height requirements shown in Table III have been prepared.

PART V

TABLE III

WAVE HEIGHT ABOVE MEAN SEA LEVEL

Wave Height Feet	60	75	90	96
Min. Wave Length Feet	420	530	630	670
Astronomical Tide	2.0	2.0	2.0	2.0
Meteorlogical Tide	6.0	6.0	6.0	6.0
Rise in Water Surface	6.3	7.4	9.5	10.1
Half Wave Height	30.0	37.5	45.0	48.0
Total Ht. Above MSL	44.3	52.9	62.5	66.1
Clearance Below E. 67.0	22.7	14.1	4.5	0.9

Preliminary evaluations indicated that a height for the lowest elements of the platform itself above mean sea level of 67 feet was desirable. In view of all uncertainties concerning maximum waves, a single wave with a height of 90 feet seems possible. If the bottom of the platform is at Elev. 67, a 4.5 ft. clearance for the crest of such a wave is provided. Further, as shown in Table III, bottom of platform at Elev. 67, provides clearance for a 96 foot high wave.

The important conclusions from this report are that the wave force is independent of the water depth and that the maximum force is exerted by the wave with the minimum stable wave length.

When the supporting legs of the Tower interfere with the passage of a wave, the energy absorbed, or the force on the legs, is also constant.

PART VI

FATIGUE, EMBRITTLEMENT AND VIBRATIONS

Any structural member subject to tensile stresses caused by loading conditions which repeat themselves can fail due to fatigue. The type of structures herein recommended for the Texas Towers include a bracing system which is subjected to such conditions. Therefore, design criteria must be established which preclude the possibility of fatigue failure. The primary loading conditions which cause repeated tensile stresses in the bracing system are wind and wave forces. As the stress which a structural member can endure is a function of both the number of repetitions and the magnitude of the stress, the approximate number of repetitions of the larger stress magnitudes during the entire life expectancy of the Texas Towers must be evaluated. For this purpose the life expectancy can be assumed to be 50 years. The number of the stress repetitions within 50 years can be approximated by an examination of the daily North Atlantic weather maps of the past ten years and listing the total duration of all storms with wind velocities over 40 miles per hour.

Assuming that all storms in the future 50 years will be similar to the storms of the last 10 years, each wave height in the stairway approximation can be associated with particular wave and wind forces on the structure and in turn cause certain tensional stresses in the bracing system. In this way the number and magnitudes of stress repetitions due to wind and wave forces throughout the total expected life of the structure can be compared with the fatigue stress characteristics for the structural material of which the bracing system is fabricated.

DESIGN AND BRACING SYSTEM VARIABLES

The design of the bracing system takes into account the affect of the following variables:

(A) Stress concentrations
(B) Size effect and stress distribution
(C) Corrosion fatigue
(D) Notch sensitivity
(E) Surface conditions and coatings
(F) Stress history
(G) Inclusions and directional properties
(H) Residual stresses
(I) Grain size
(J) Speed effect
(K) Temperature effect
(L) Cold work
(M) "Cocoa" or fretting corrosion

The effects on the fatigue strength of a structural member listed under (A) through (F) and (M) are of major importance whereas those listed under (G) through (L) are of minor importance.

The design of the bracing system must take into consideration the possibility of failure by brittle fracture. A brittle fracture can occur under the influence of a combination of the following factors:

(A) Low temperature
(B) High rate of strain
(C) Stress concentration
(D) Large values of stress

Low temperatures and dynamic loading can occur simultaneously at the locations of Texas Towers. In order to avoid a brittle fracture, serious stress concentration factors must be minimized and probability of formation of fatigue cracks of appreciable size avoided by careful and conservative design of the bracing system.

SELF-INDUCED VIBRATIONS

During a storm the flow of air between the dome structures will have an increased velocity due to the "Venturi effect" and self-induced vibrations due to the "Karman vortex trail" may be set up. However, it is believed that such self-excited vibrations will not

BECOME SERIOUS BECAUSE OF THE FLEXIBILITY AND LOW MASS OF THE DOMES. KARMAN VORTICES ALSO FORM WHEN A FLUID FLOWS AROUND A SHARP EDGED DISCONTINUITY IN THE FLOW STREAM. SUCH A PHENOMENON MAY OCCUR AT THE REAR SIDE OF THE TRIANGULAR PLATFORM. SHOULD AN ANALYSIS REVEAL THAT DYNAMIC VIBRATIONS COULD BECOME SERIOUS, THE APPLICATION OF "SPOILERS" MUST BE TAKEN INTO CONSIDERATION. SUCH SPOILERS CHANGE THE AERODYNAMIC FLOW PATTERN AND REDUCE OR ELIMINATE DYNAMIC VIBRATION. HOWEVER, SUCH DEVICES NECESSARILY INCREASE THE DRAG ON THE STRUCTURE. SELF-INDUCED VIBRATIONS DUE TO REPETITIVE WAVE IMPACTS ON THE LEGS WILL NOT OCCUR FOR REASONS PREVIOUSLY DISCUSSED.

ABRASION FROM WATER-BORNE SAND

THE AMOUNT AND MAXIMUM PARTICLE SIZES OF SAND SUSPENDED IN WATER CLOSE TO THE SEA BOTTOM ARE FUNCTIONS OF THE WATER VELOCITY. VELOCITIES CLOSE TO THE SEA BOTTOM ARE INDUCED BY WAVE ACTION AND BY TIDAL CURRENTS, THE FIRST BEING OSCILLATORY WITH THE PERIOD OF THE WAVE AND THE SECOND BEING TRANSILATORY IN THE DIRECTION OF THE CURRENT. UNDER THE CONDITIONS FOUND AT THE SITES AT GEORGE'S BANK AND NANTUCKET SHOALS, EITHER TYPE OF SEA BOTTOM MOVEMENT HAS VELOCITIES SUFFICIENT TO TRANSPORT SAND AND MAY CAUSE SERIOUS ABRASIVE LOSSES TO SUBMERGED STRUCTURES. HENCE, ADEQUATE PROTECTION AGAINST SUCH ABRASION OR SAND CUTTING MUST BE PROVIDED AT THESE TWO LOCATIONS.

REFERENCES USED IN PREPARING THIS REPORT

BIGELOW, H.B. AND W.T. EDMONDSON
"WIND WAVES AT SEA, BREAKERS AND SURF"
(HO 602, 1947)

DAILY, J.W. AND S.C. STEPHAN JR.
"CHARACTERISTICS OF THE SOLITARY WAVE"

HAVELOCK T.H.
"THE PRESSURE OF WATER WAVES UPON A
FIXED OBSTACLE"
ROYAL SOCIETY LONDON, VOL. 175

MINIKIN, R.R.
"WIND, WAVES AND MARITIME STRUCTURES"
CHARLES GRIFFEN AND CO., LTD., 1950

PIERSON, W.J.
"PRACTICAL METHODS FOR OBSERVING AND
FORECASTING OCEAN WAVES BY MEANS OF
WAVE SPECTRA AND STATISTICS"

RUSSELL, R.C.H. AND D.H. MCMILLAN
"WAVES AND TIDES"
PHILOSOPHICAL LIBRARY INC., N.Y.

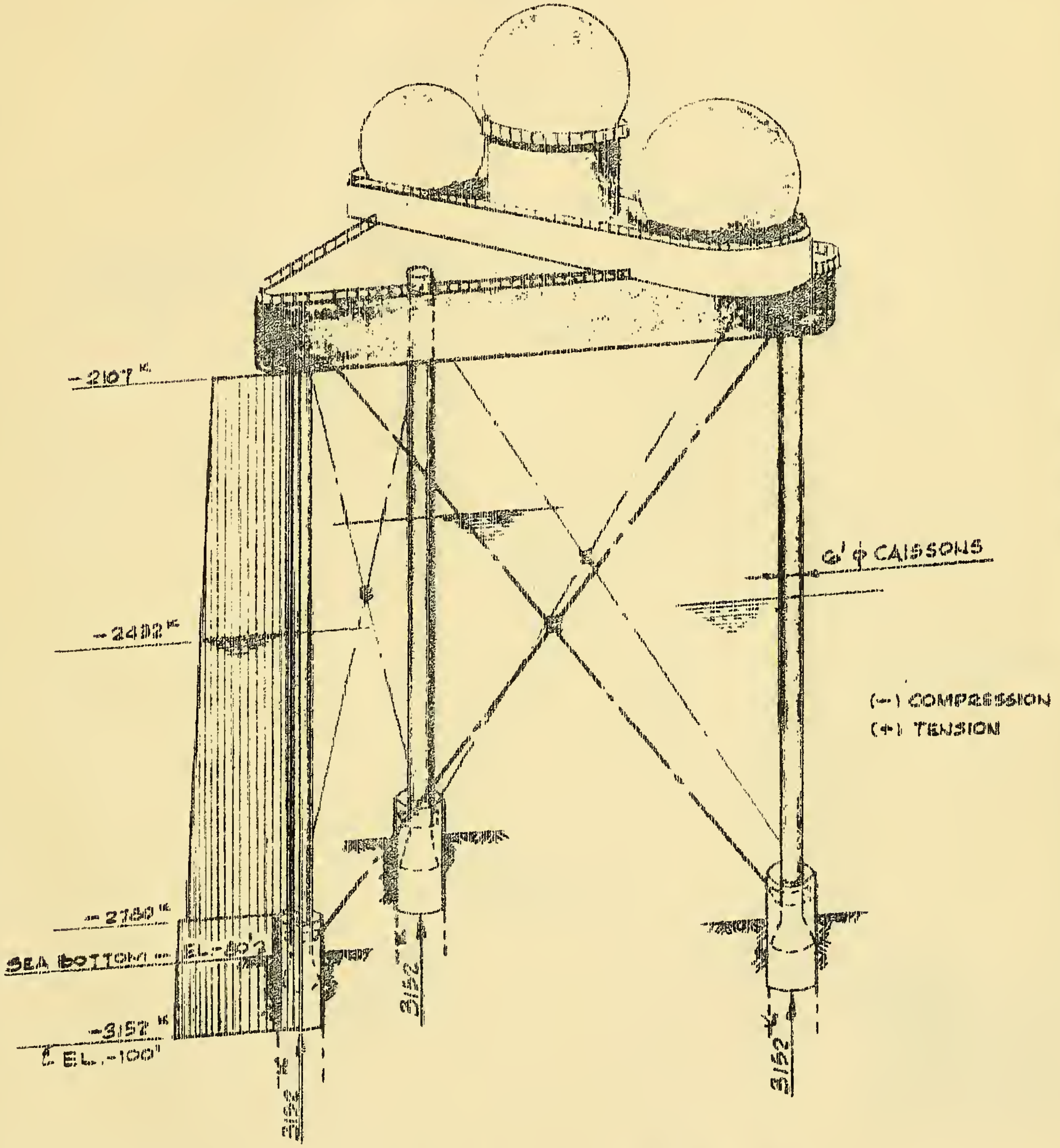
UNITED STATES NAVY DEPARTMENT HYDROGRAPHIC
OFFICE, PUB. 234
"BREAKERS AND SURF - PRINCIPLES IN FORECASTING"

UNITED STATES NAVY DEPARTMENT (HO 601)
"WIND, SEA AND SWELL"
THEORY OF RELATIONS FOR FORECASTING"
H.V. SVERDUP AND W.H. MUNK

PLATE # 2

DATE: 9/26/54
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM EL.-80'-0"



NOTE: THE VERTICAL REACTIONS INCLUDE 607K LIVE LOAD.

FORCE DIAGRAM

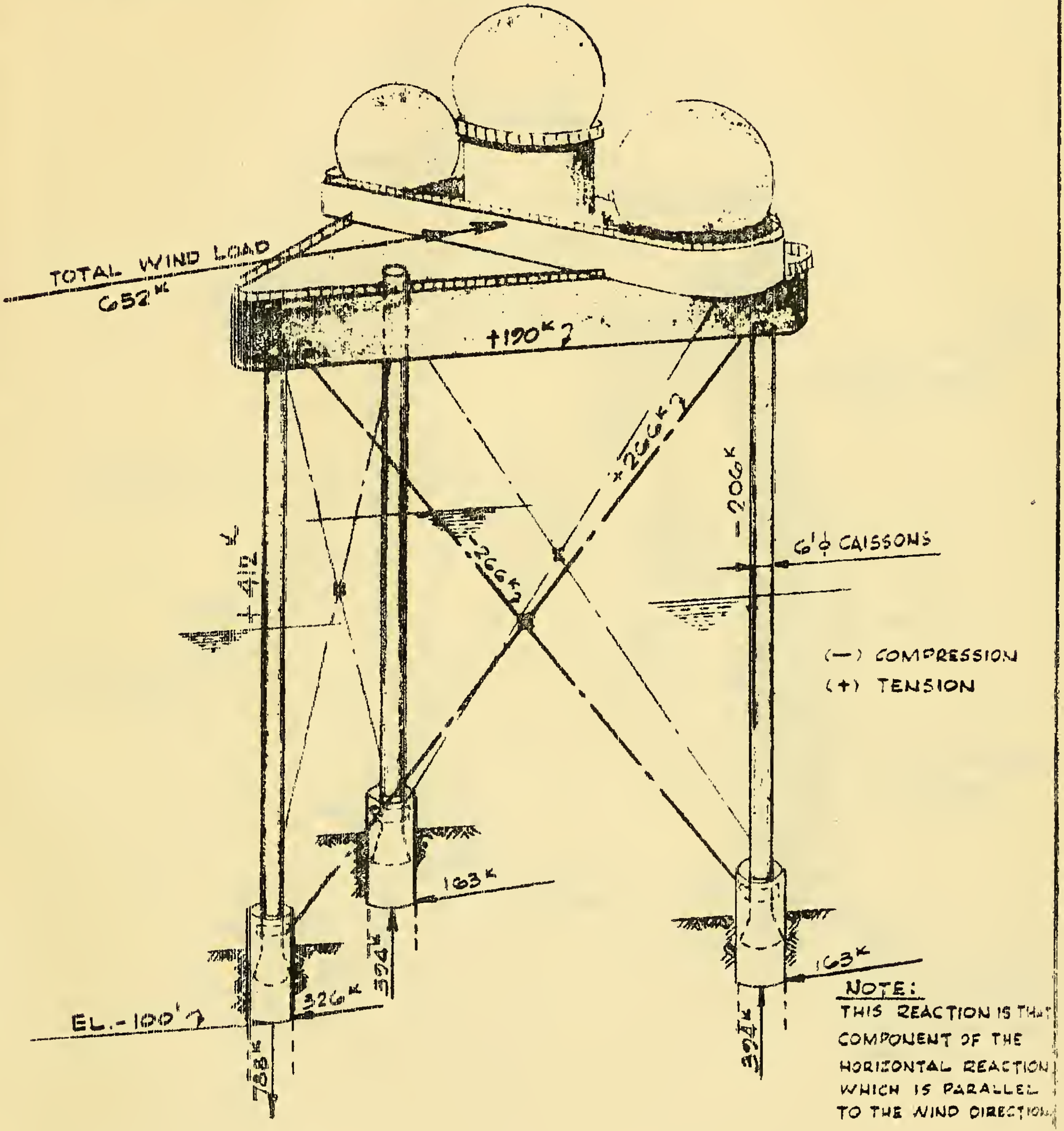
DUE TO DEAD LOADS & VERTICAL LIVE LOADS

CRITERION 3

PLATE # 3

DATE: 7/26/54
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM EL. -80'-0"



FORCE DIAGRAM

LOADING DUE TO 125 M.P.H. WIND

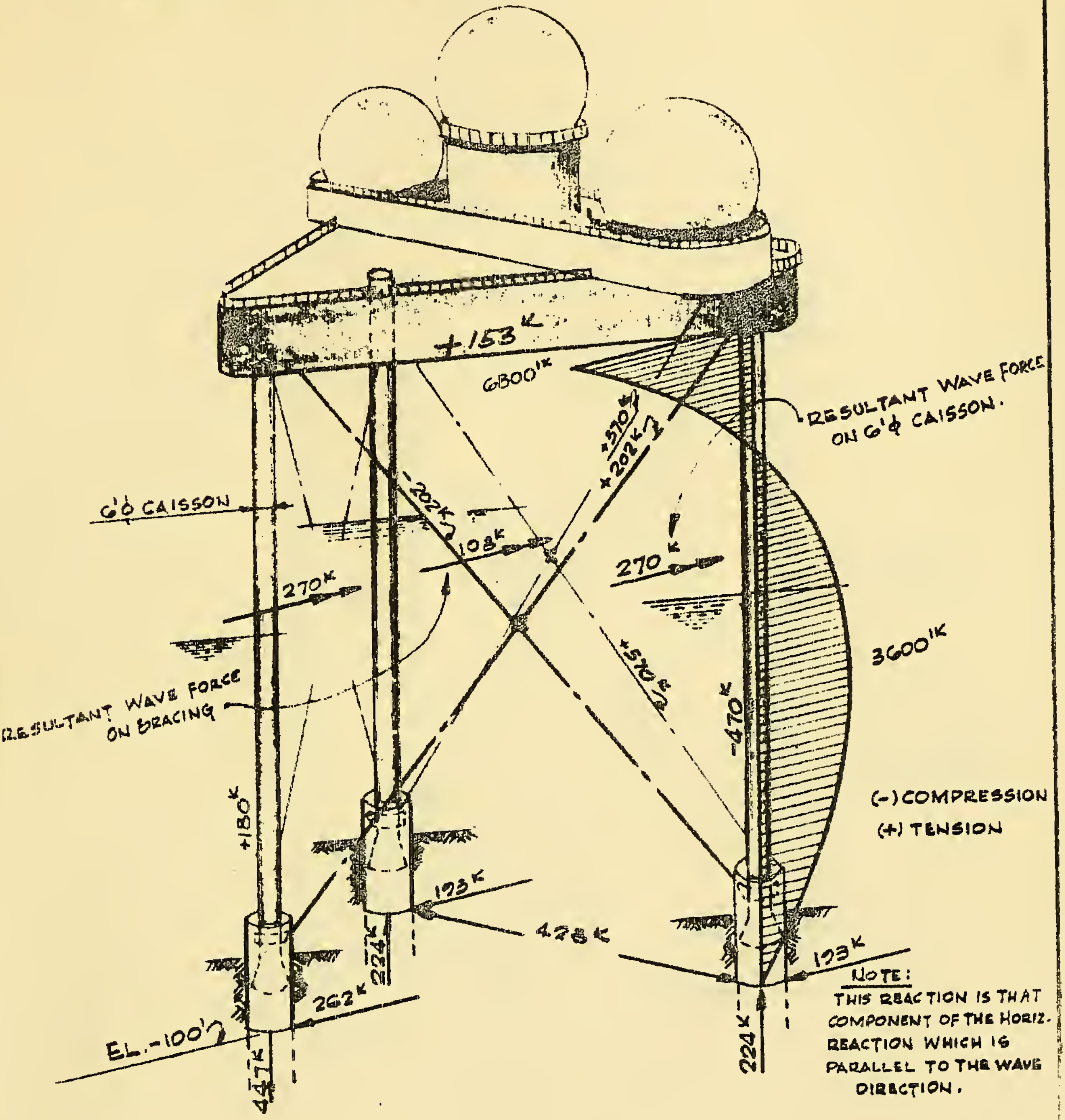
CRITERION 3

[illegible]

PLATE # 4

DATE: 2/26/54
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM EL.-80'-0"



NOTE: THIS REACTION IS THAT COMPONENT OF THE HORIZ. REACTION WHICH IS PARALLEL TO THE WAVE DIRECTION.

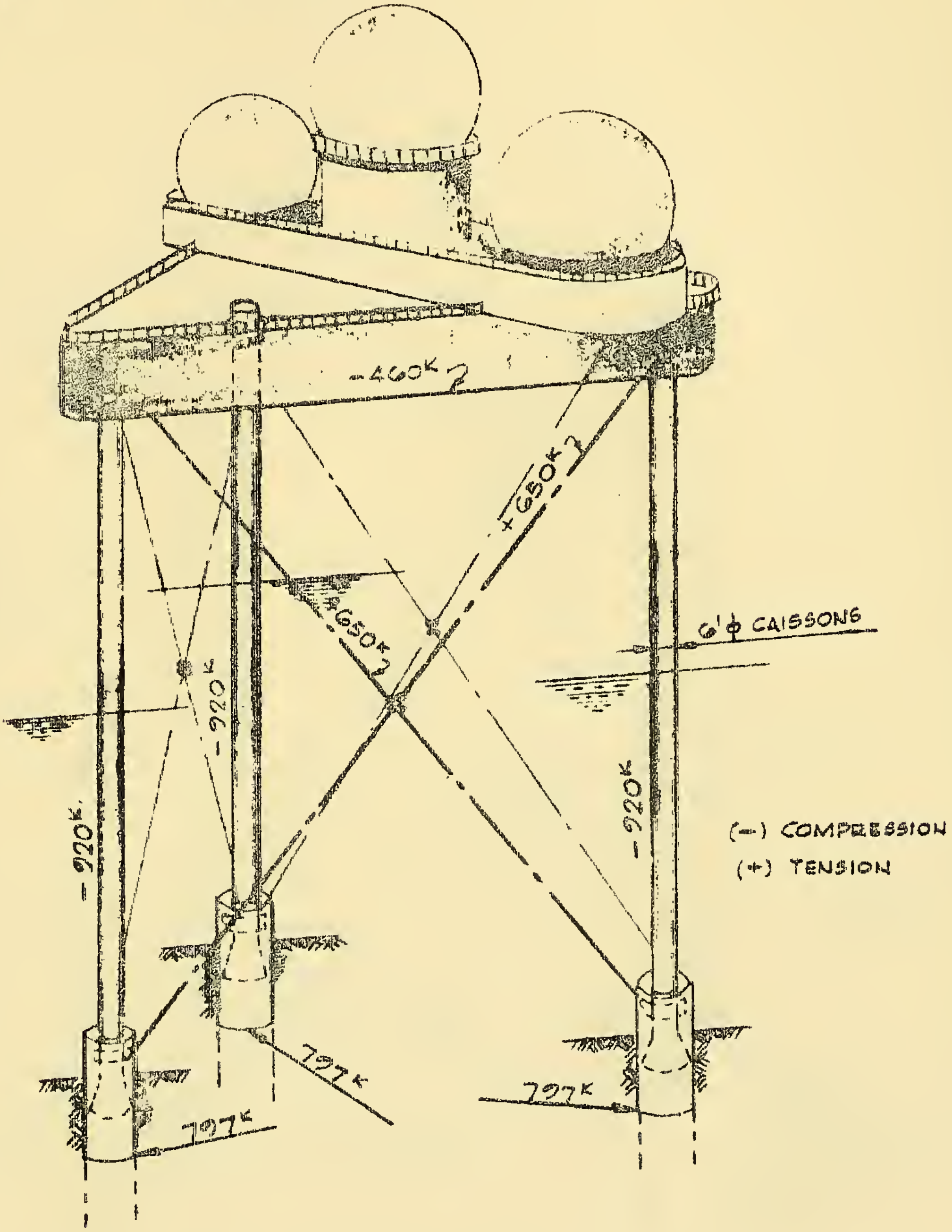
FORCE DIAGRAM

LOADING DUE TO 35' BREAKING WAVE
CRITERION 3

PLATE* 5

DATE: 9/26/54.
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM EL. -80'-0"

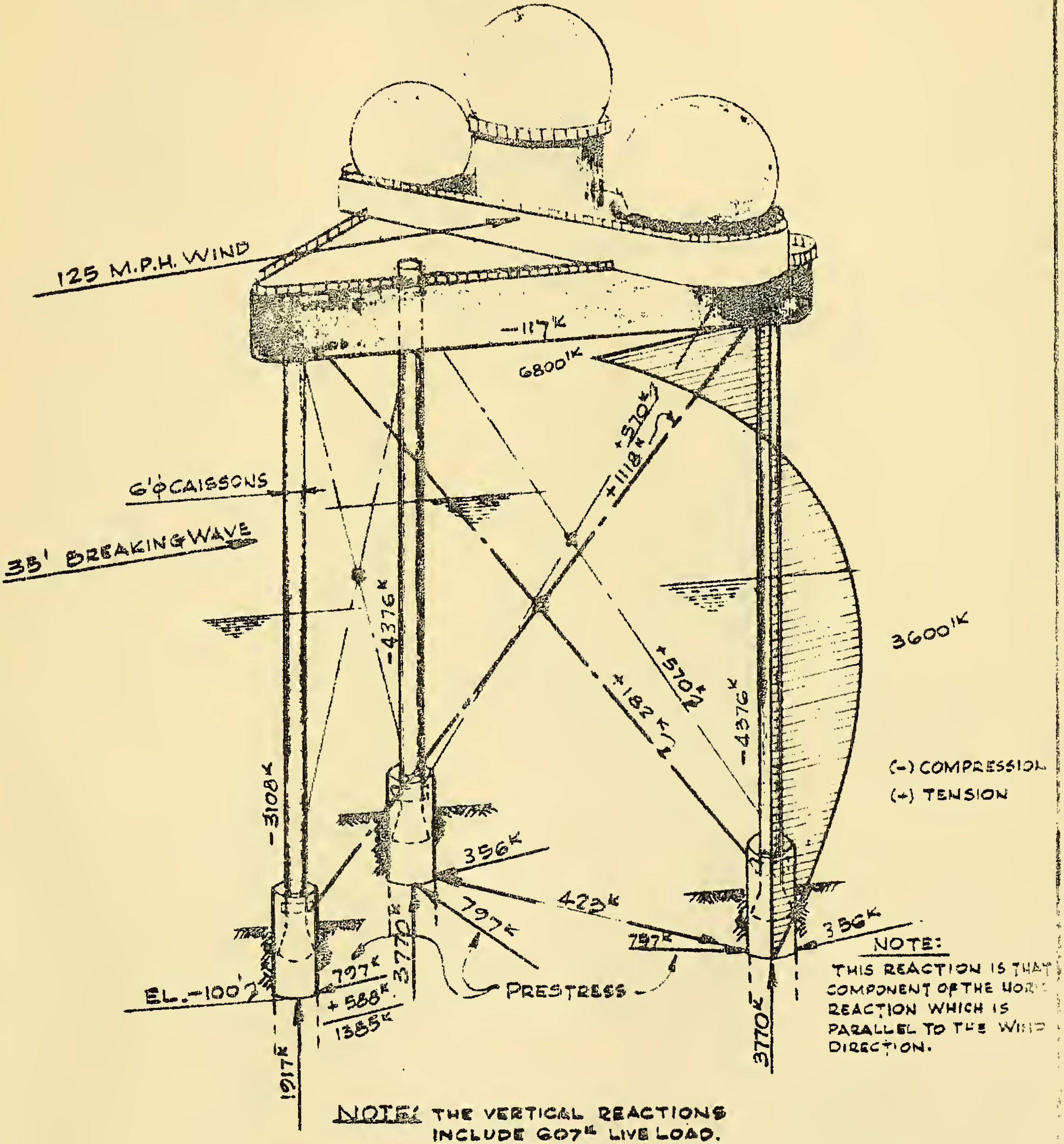


FORCE DIAGRAM

PRESTRESS LOADING
CRITERION 3

DATE: 9/26/54
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM – EL. -80'-0"



NOTE:
THIS REACTION IS THAT COMPONENT OF THE HOR REACTION WHICH IS PARALLEL TO THE WIND DIRECTION.

NOTE: THE VERTICAL REACTIONS INCLUDE 607K LIVE LOAD.

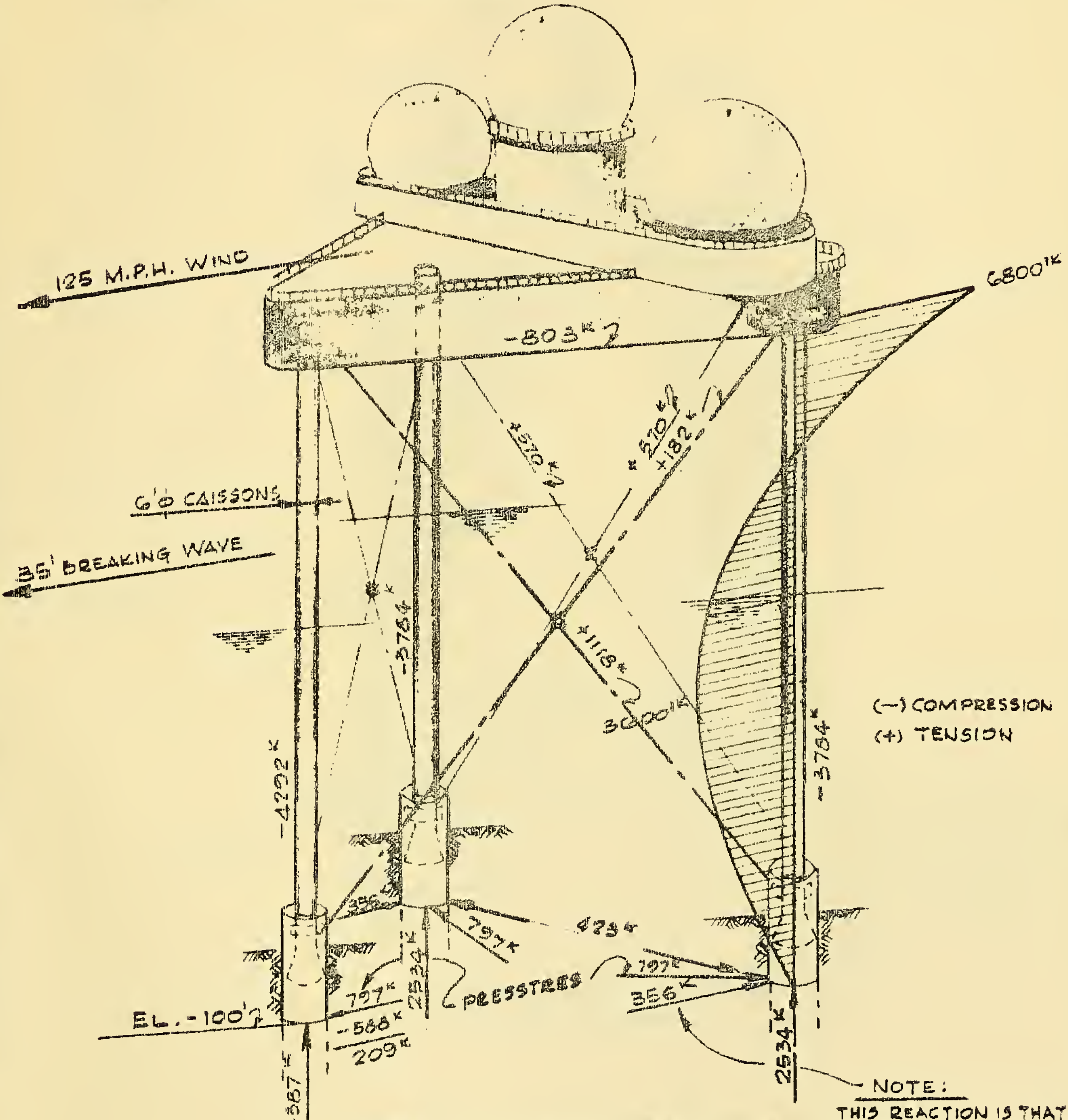
FORCE DIAGRAM

SUPERPOSITION OF:
DEAD LOADS & VERTICAL LIVE LOADS
PRESTRESS LOADING
WIND & WAVE AS SHOWN
CRITERION 3

PLATE # 7

DATE: 2/26/54
DES.: JP
CHK.: FER

T.T. 2 GEORGES SHOAL
T.T. 3 NANTUCKET SHOAL
SEA BOTTOM - EL.-80'-0"



NOTE: THE VERTICAL REACTIONS INCLUDE 607 K LIVE LOAD.

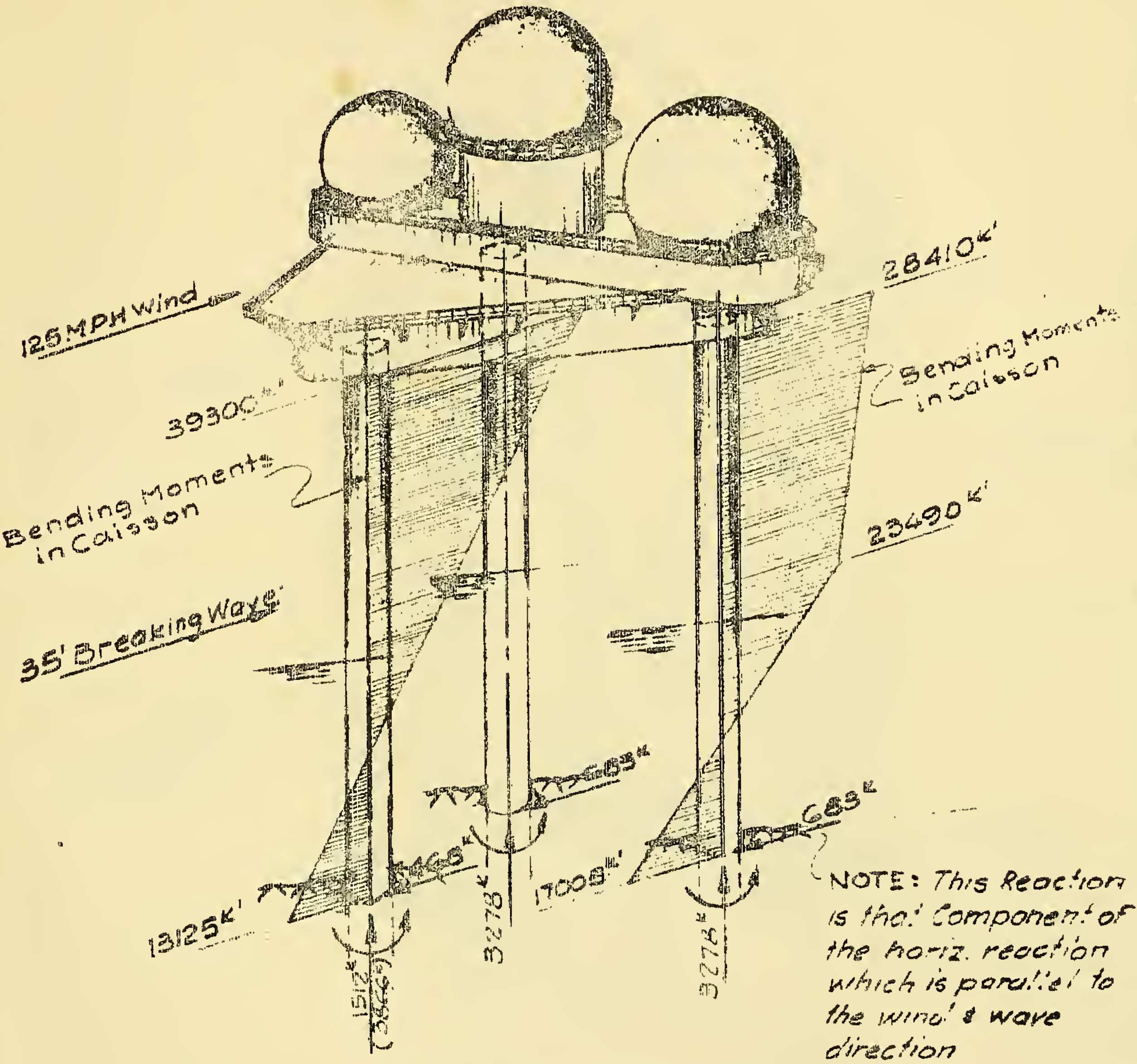
NOTE: THIS REACTION IS THAT COMPONENT OF THE HORIZ. REACTION WHICH IS PARALLEL TO THE WIND DIRECTION.

FORCE DIAGRAM

SUPERPOSITION OF:
DEAD LOADS & VERTICAL LIVE LOADS
PRESTRESS LOADING
WIND & WAVE AS SHOWN
CRITERION 3

PLATE # 9
DATE: 9/26/54
DES.: ..
CHK.: EEP

TRI-CASHES LEDGE
SEA BOTTOM EL. -30



NOTE: This Reaction is that Component of the horiz. reaction which is parallel to the wind & wave direction

NOTE: THE VERTICAL REACTIONS INCLUDE 607^K LIVE LOAD.

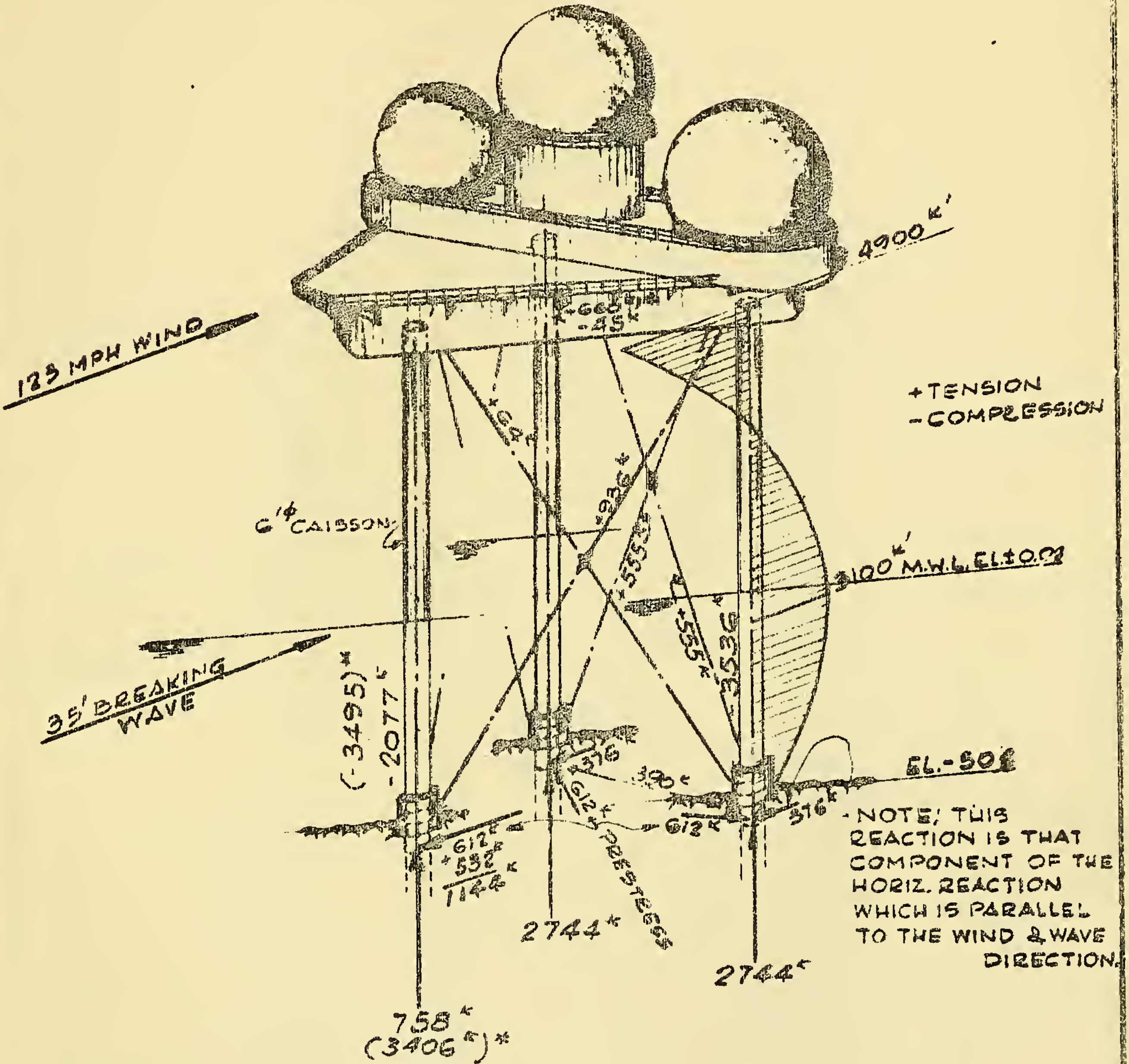
FORCE DIAGRAM

Superposition of
Dead Loads & Vertical Live Loads
Wind & Wave as Shown.

( )* These are critical values for wind & wave in the opposite direction.

DATE: 9-26-54
DES. I.L
CHK. FER

III-CASHES LEDGE
SEA BOTTOM - EL.-50'



NOTE: THE VERTICAL REACTIONS INCLUDE
A LIVE LOAD OF 607k

FORCE DIAGRAM

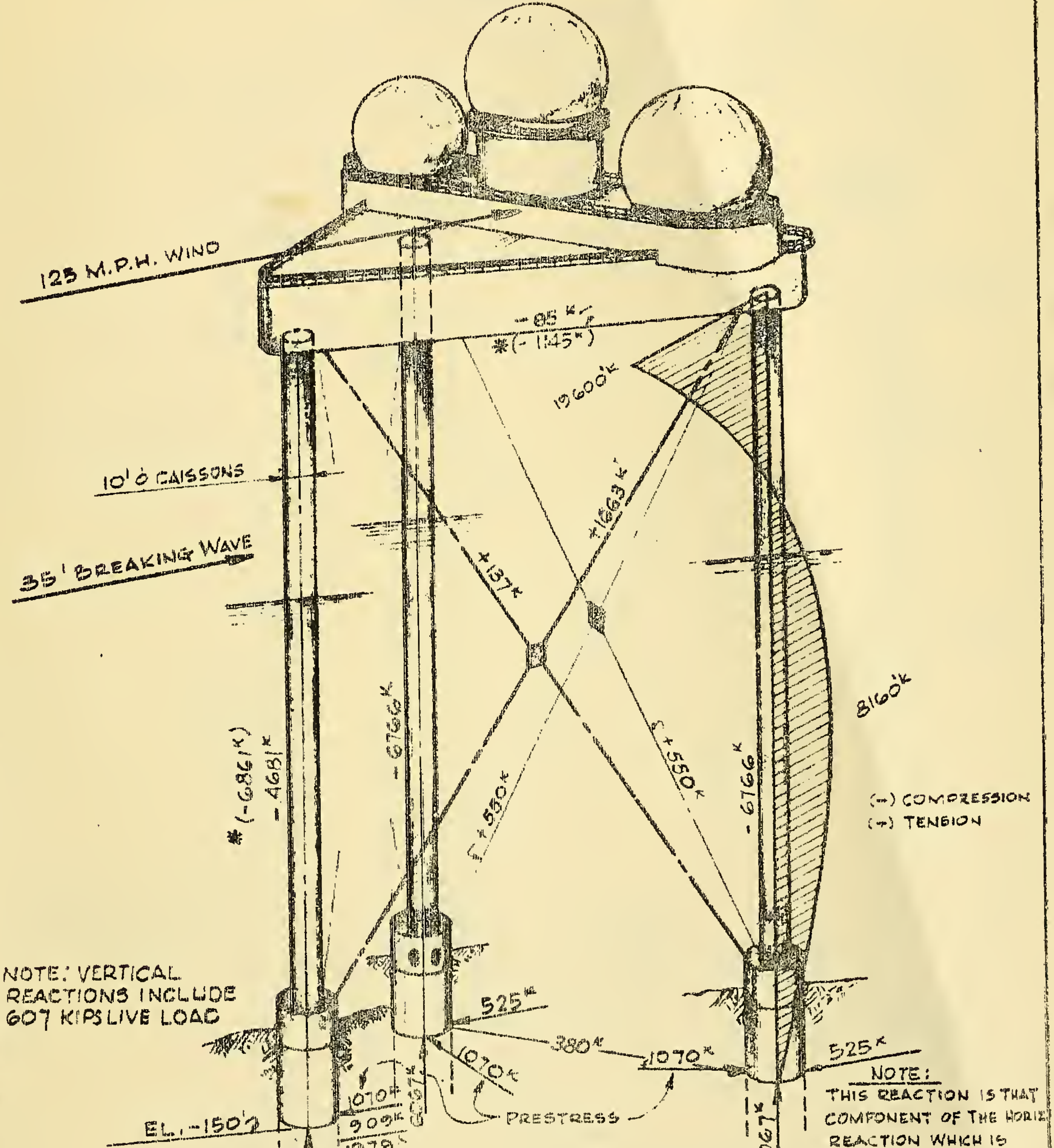
SUPERPOSITION OF
DEAD LOADS & LIVE LOADS
PRESTRESS LOADING
WIND & WAVE AS SHOWN

( )* - THESE ARE CRITICAL VALUES FOR WIND & WAVE IN THE OPPSITE DIRECTION.

PLATE # 11

DATE: 9-26-54
DES. JP
CHK. FER

T.T. 5 - BROWNS BANK
SEA BOTTOM - EL. -130'-0"



FORCE DIAGRAM

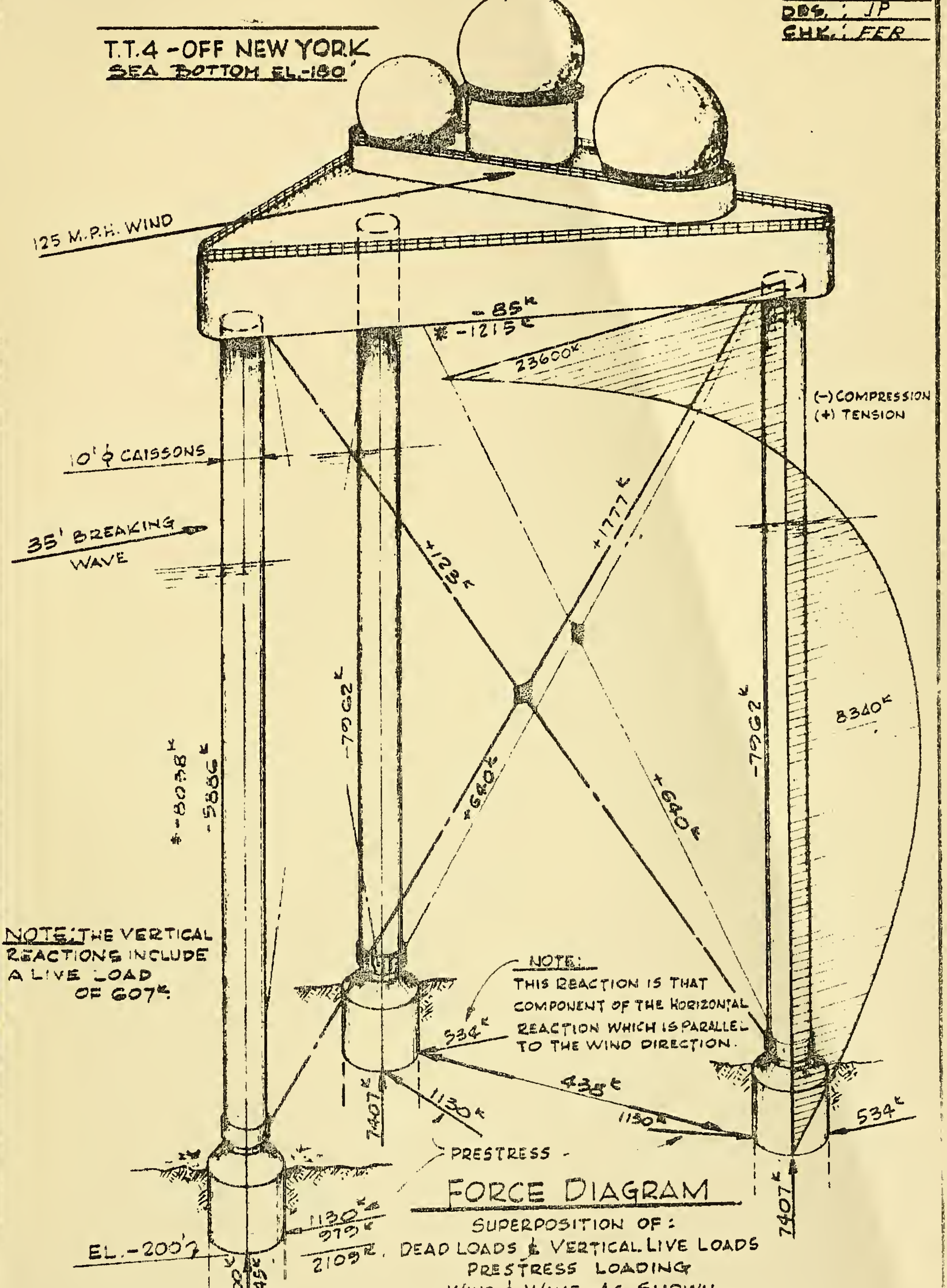
SUPERPOSITION OF:
DEAD LOADS & VERTICAL LIVE LOADS
PRESTRESS LOADING
WIND & WAVE AS SHOWN
CRITERION 3

* THESE ARE CRITICAL VALUES FOR WIND AND WAVE IN THE OPOSITE DIRECTION

IC.

PLATE # 12
DATE: 9/26/54
DRS.: JP
CHK.: FER

T.T.4 - OFF NEW YORK
SEA BOTTOM EL.-180'



NOTE: THE VERTICAL REACTIONS INCLUDE A LIVE LOAD OF 607ᵏ.

NOTE: THIS REACTION IS THAT COMPONENT OF THE HORIZONTAL REACTION WHICH IS PARALLEL TO THE WIND DIRECTION.

FORCE DIAGRAM

SUPERPOSITION OF:
DEAD LOADS & VERTICAL LIVE LOADS
PRESTRESS LOADING
WIND & WAVE AS SHOWN
CRITERION 3

* THESE ARE CRITICAL VALUES FOR WIND AND WAVE IN THE OPPOSITE DIRECTION.