# Static Analysis of Oil Platforms in Deep Water using Dynamic Load Stations

# التحليل الاستاتيكى لمنصات البترول فى المياه العميقة باستخدام محطات الأحمال الديناميكية

**By**

M. Naguib, S. Selim, S. Lotfy

Structural Eng. Dept., Mansoura University, Mansoura, Egypt

**الخلاصة:**

إن الهدف الرئيسى لهذا البحث يتركز فى التحليل الاستاتيكى لمنصات البترول فى المياه العميقة باستخدام محطات الأحمال الديناميكية ونظراً لأن التحليل الديناميكى للمنشآت الكبيرة لمتطلبات الزمن يكون معقد جداً خاصة مع الأحمال الديناميكية المتعددة فقد حاولنا إجراء التحليل الاستاتيكى باستخدام صياغة محطات الأحمال ونظراً لأن الأحمال الرئيسية لهذا النوع من المنشآت بالإضافة الى الحمل الذاتى للمنشأ تتمثل فى ضغط الأمواج و قوة تيار المياه وأحمال الرياح و قوى الرفع لأعلى حيث تم إعداد برنامج على الحاسب الآلى لتوليد الأمواج باستخدام معادلات مورسن مع حساب جميع الأحمال المؤثرة على المنشأ وقد تم إجراء التحليل الاستاتيكى باستخدام طريقتين للمقارنة وهما طريقة العناصر المحددة والمتمثلة فى برنامج ANSYS وطريقة تصغير الطاقة المتمثلة فى برنامج تم اعداده وكانت أهم النتائج أن استخدام محطات الأحمال الديناميكية فى اجراء التحليل الاستاتيكى بدلاً من التحليل الديناميكى لمنصات البترول اضافة جيدة فى هذا المجالو فى النهاية تم تدوين خلاصة النتائج ومناقشتها.

## ABSTRACT

The main objective of this research is concerned about the static analysis of oil platforms in deep water using dynamic load stations. The dynamic analysis for large structures in time domain is very complicated and time-consuming, especially with many various dynamic loads.To reduce the labor, the static analysis using the dynamic load station technique is carried out instead time domain dynamic analysis.The main loads for this type of structures including self-weight and super-imposed loads are water wave pressure, water current, wind loads and uplift forces. A FORTRAN program constructed by the author is used to generate the water waves and their properties. This program usesStokes wave theories and Morison equations. The static analysis is carried out using two methods for comparison. These methods are a finite element method using ANSYS program and other method as a computer program proposed by [1] using the minimization of total potential energy. Finally, the major conclusion verified that, the dynamic load station technique for static analysis is suitable technique to deduce the critical sway and critical internal forces of oil platforms.Also, the other summary and discussion of results are presented.

# 1- INTRODUCTION

The development of oil platforms has resulted in a demand. The total number of offshore platforms in various gulfs and oceans of the world is growing up these days. The most platformsare considered as fixed base types and cantilever pole. The Stokes wave theories and Morison equations[2] are used for determination of wave kinematics and wave forces acting on platforms. The Stokes' second order wave theory is used because, it is accommodating for Egypt sea conditions. The nonlinearity in wave drag forces and wave structure interaction is taken into consideration for making the required analysis. The aim of offshore structural engineering is to produce structures which are safe, functional, economical and able to resist the forces included by man and environmental conditions. The analysis is carried out for main loads including self-weight, both water wave and water current for submerged part of structure, and wind loads for structural's part above water. Also, the secondary loads as uplift forces and thrust forces in structural elements are taken. ANSYS and computer program proposed by [1] are used. The energy method based on the minimization of the total potential energy (TPE) using conjugate gradient technique is used.The dynamic load stations are used to carry out the static analysis. The analysis behavior for the platforms with various responses is presented. The study is carried out for both static and dynamic to make a comparison. Finally, the conclusion including the new technique (dynamic load stations) is summarized.

# 2- DYNAMIC LOAD STATION TECHNIQUE

This technique is a new one used as instead case of dynamic time domain analysis. With reference to Fig. (1), the analysis is carried out according to the following steps:

1- The configuration of structure including the total description of joints, and members with all geometric properties is prepared by proposed computer program for this subject.
2- The generation of wave due to Stokes theories with all load properties and self-weight and super-imposed loadon platform including wind load and other loads are prepared.
3- The all load types (self-weight, super-imposed load, wind loads, thrust forces in structural members and uplift forces) are considered as fixed cases.
4- The water wave pressure is the only case of loading computed using the dynamic load station technique.
5- The static analysis for all previous described case of loading with first station is carried out using the (TPE) method.
6- To carry out the static analysis after preparing structure geometry and loading the following steps [3, 4, 5, 6, 7 and 8] is used:
6.1 Calculate the elements of the stiffness matrix for each flexural member in global co-ordinates, and compute the scaling matrix, H, using equation (1)

$$H = \text{diag}\left\{k_{11}^{-0.5}, k_{22}^{-0.5}, \ldots\ldots, k_{nn}^{-0.5}\right\} \qquad (1)$$

Where;
$k_{ii}$ is the $i^{th}$ element along the leading diagonal of the stiffness matrix.
6.2 Calculate the elements in the gradient vector of the TPE, using:

$$g_s = \sum_{n=1}^{f_j}\left(\sum_{r=1}^{12} K_{sr}X_r\right)_n - F_n \qquad (2)$$

Where;

$f_j$ is the number of flexural members meeting at joint j,

$K_{sr}$ is the element of stiffness matrix of a flexural member in global co-ordinates,

$X_r$ is the element of displacement vector of a flexural member, and

$F_n$ is the element in the applied load vector.

6.3 Calculate the Euclidean norm of the gradient vector, $R_K = \left(g_K^T g_K\right)^{0.5}$, and check if the problem has converged. If $R_K \le R_{min}$ stop the calculations and print the results. If not, proceed to (6.4).

6.4 Calculate the elements in the descent vector.This vector has an initial value expressed as:

$V_0 = -Hg_0$ (3)Where;

$g_0$ is the first gradient vector.

The descent vector $V_K$ at any iteration $K^{th}$ can be expressed as:

$V_K = -Hg_K + \beta_{K-1}V_{K-1}$ (4)

Where;

$$\beta_{k-1} = \frac{[g]_K^T [H]^T [H][g]_K}{[g]_{K-1}^T [H]^T [H][g]_{K-1}} \qquad (5)$$

6.5 Calculate the coefficients in the step length polynomial from:

$$C_1 = \sum_{n=1}^{f}\sum_{s=1}^{12}\sum_{r=1}^{12}\left(X_{k_s}K_{sr}V_{k_s}\right)_n - \sum_{n=1}^{p} F_n V_{k_n} \quad (6\text{-a})$$

$$C_2 = \sum_{n=1}^{f}\sum_{s=1}^{12}\sum_{r=1}^{12}\left(\frac{1}{2}V_{k_s}K_{sr}V_{k_r}\right)_n \qquad (6\text{-b})$$

6.6 Calculate the step-length S using Newton's approximate formula as:

$$S_{i+1} = S_i - \frac{2C_2S_i + C_1}{2C_2} \qquad (7)$$

Where: i is an iteration suffix and $S_{i=0}$ is taken as zero

6.7 Update the displacement vector using equation (8)

$X_{K+1}=X_K+S_K$ (8)

Where, $V_K$ is the descent vector at the $K^{th}$ iteration, $X_K$ in displacement space and $S_K$ is the step length determining the distance along $V_K$ to the point where TPE is a minimum.

6.8 Determine the new gradient vector using equation (2)

6.9 Calculate the Euclidean norm of the gradient, $R_K = \left(g_K^T g_K\right)^{0.5}$, and check if the structure has converged. If the convergence criterion is satisfied ($R_k \le R_{min}$) go to 6.11, otherwise continue with 6.10.

6.10 Compute the descent (direction) vector, V, using equation (4), and then return to 6.5

6.11 Evaluate the final configuration of the structure using equation (8) to obtain the joint displacements and rotations in the local and hence in the structure axes.

6.12 Determine the member end forces for each flexural member

7- Repeat the previous step with a new load station.

8- The response for all dynamic stations are tabulated for some cases and drawn for others.

9- The obtained results are studied and summarized.

## 3- LOAD CASES

In this study, the gravity loads, static deck loads, buoyancy(uplift forces), thrust forces, wind forces on the part of structure located above the water surface, current and wave forces are considered.

## 3.1- Gravity Loads

Two types of gravity loads are taken into consideration. They are:

1-The self-weight (dead load)contains all fixed items as cranes, conductors, flare boom, jacket structure, equipment, and buildings weights. The intensities of dead loads per square meter for main deck and cellar deck are considered as 0.25ton, and 0.17088 ton, respectively [9].The total self-weight of platform having a dimension of 50×50ms is 15886 tons.

2-The superimposed loads (Live loads) are movable and temporary loads in nature such as operating weight of liquid contained inside equipment, open area live loads on floor, operating loads of pedestal crane and operating loads for drilling activity and well service operations. The total super-imposed load is considered as $3.5t/m^2$ and $1.75t/m^2$ for the main deck and for the cellar deck, respectively [9].

## 3.2- Environmental Loads

### 3.2.1 Wind load

Wind load acts on the deck and the legs parts above sea surface. The calculus of the wind forces is recommended by [10]. It was found to be:

$$F = \frac{1}{2}\rho_a C_d D U^2 \quad (9)$$

Where;

$F$ is the force per unit length,

$\rho_a$ is the air density,

$C_d$ is the drag coefficient,

$D$ is the member width, and

$U$ is the wind velocity

### 3.2.2 Wave and current loads

The platform is exposed to directional periodic wave. Wave forces, $F_N$ per unit length of a slender vertical rigid component and no motion, may be expressed as:

$$F_N=0.5\rho C_d D|U|U+C_m\rho A a \quad (10)$$

Where;

$\rho$ is the mass density of fluid,

$C_d$ is the drag coefficient,

$D$ is the member diameter or typical cross section dimension,

$A$ is the member's cross section area,

$U$ is the effective velocity of the flow resolved normal to the member,

$a$ is the acceleration of the flow resolved normal to the member, and

$C_m$ is the inertia coefficient

The effective fluid velocity U is the sum of current velocity and the horizontal wave particle velocity. Various wave kinematic models and the corresponding force coefficients are discussed by [11].

### 3.2.3 Buoyant forces

Buoyant forces are only applied to objects (or portions of objects) that lie above the mud line and below the wave surface. Buoyant forces consist of a uniform projected Z-direction load applied to objects that are not vertical and concentrated compressive axial forces applied to the ends of all objects.

#### 3.2.3.1 Uplift force (uniform load)

The magnitude of the uplift force is calculated as:

$$F_{Bz} = \gamma V \quad (11)$$

Where;
$F_{Bz}$ is a uniform load in the projected Z-direction,
$\gamma$ is theweight density of the water, and
V is thedisplaced volume per unit length of the object.

### 3.2.3.2 Concentrated compressive loads at object ends (thrust force)

The magnitude of the concentrated compressive axial load at each end of each object is calculated as:

$$P=\gamma Ah \quad (12)$$

Where;
P is the concentrated compressive axial load,
$\gamma$ is the weight density of the water,
h is the height from water surface to the required end of the element, and
$A_c$ is the cross sectional area to which the load is applied.

## 5- ANALYSIS CONSIDERATIONS

### 5.1 Geometry and properties of oil platform

In the present study, a three dimensional fixed oil platform made up of steel structure is used for the analysis. Total height of the platform is 106m. The platform consists of eight steel lattice columns installed in a water depth of 92m. The deck is modeled as a space truss. The deck consists of two levels which are main and cellar deck. The space truss of the decks and columns consist of horizontal, vertical and diagonal members. For the deck, all members are tubular sections except for the horizontal members which are I- Beam sections. The eight lattice column members are tubular sections. The mathematical model for platform has1522 joints, 6477 members and 8748 degrees of freedom.All structural members are made from steel with the following properties;

$\rho$=7.85 t/m$^3$, E=2.1×10$^7$ t/m$^2$, and $F_y$=35500 t/m$^2$.

Where;

$\rho$ is the density of the steel,
E is the modulus of elasticity of steel, and
$F_y$ is yield stress.
All properties of all members for main and cellar deck are given in Table (1). Theisometric view of the platform is shown in Fig. (2).

### 5.2 Load stations

With reference to Fig. (1), the dynamic load stations have been carried out for movable wave. With wave having a total length of 322.16m, 207 stations with a 2m step are considered.The wave phase angle is considered as 0 degree (horizontal projection). The wave crest starts from a fixed point which has co-ordinate (-206.0,-20.0) according to axes of platform shown in Figs. (3-a and 3-c).

The environmental conditions in Egypt were investigated by [12]. It was found to be the wave height is 12.1m, the wave return period is 14.4 sec, the wind velocity is 25.1m/sec, and the current velocity at sea surface and the mud surface are 0.75 and 0.5m/sec, respectively. All types of loads are considered as fixed cases except the water wave pressure which is calculated each dynamic load station. Figure(1) shows the technique of the stations. For stations number (26,76 and

126), the wave crest starts from a stations which have co-ordinates (-156,-20), (-53,-20), and(44,-20), respectively.

### 5.3 Dynamic case

Dynamic analysis has been done for the same case of loading of the dynamic load station technique. The structure first natural frequency was found to be 0.328962HZ. The damping is assumed to be about 1.5%. The analysis has been carried for about 18sec (total time) with time step equal to 0.02sec.

## 6- ANALYSIS OF RESULTS

The dynamic load stations technique to indicate the response of the structure due to the flow of waves is carried out. The technique is used to distinguish the response at critical joints. Figures (3-a, 3-b, 3-c, 3-d, and 3-e) involvethe joints and the elements which have been studied. Variations of the lateral displacements (X-and Y-directions) are shown in Figs. (4-a, and 4-b), and Tables (2 and 4). It can be concluded that:

a) Joint 1 has the maximum sway in X-direction (0.2867176m) at station number 89.
b) Joint 1 has the maximum sway in Y-direction (0.1958m) at station number 93.
c) The thrust forces have great effect on the response.
d) The structure responses behave with a period equal to the wave period.
e) The structure joints behave sinusoidal in X- and Y-directions.
f) The lateral sway in Y-direction can be neglected, with neglecting the compressive forces.

Variations of internal forces are shown in Figs. (6-a, and6-b) and Tables (3, and 5). From these figures and tables, it can be concluded that:

a) Element 841 has the maximum tensile normal force (2339.942 tons) at station number 86.
b) Element 921 has the maximum compressive normal force (-1832.35) at station number 89.
c) The variations of internal forces are sinusoidal.

Time domain analysis is carried out to examine the difference in the results between the load station and time domain techniques.From Figs. (6-a, to7-f), it can be concluded that the response of time domain analysis vibrates about the results of the dynamic load stations. There is a remote difference between two methods.

## 7- CONCLUSION

Dynamic load station technique for static analysis is a suitable technique to deduce the critical sway and critical internal forces of offshore structures. The obtained results using this technique are very close to those results obtained using a time domain dynamic analysis. The effort in this technique is little in compared with dynamic analysis. Also, time saving for analysis is significant. Among environmental conditions, waves are the most important one contributing to the response of platforms. The structure exhibits the sinusoidal behavior due to wave effect with the same wave length with neglecting inertia forces and damping forces.

## 8- REFERENCES


1. **Naguib, M.**"Buckling Strength and Dynamic Response of Guyed Towers" Ph.D. Thesis, Struct. Eng. Dept., Mansoura University, Mansoura, Egypt, 1989.

2. **Morison, J.R.,Obrien , M.P., Johnson , J.w., and Schaaf, S.A.** , "The Force Exerted by the Surface Waves on Piles. " petrol. Trans. , AIME , vol. 189. PP149-154, 1950.

3. **Buchholdt H.A.** "An Introduction to Cable Structures", Cambridge University, Press 1985.

4. **Buchholdt, H. A.,** " Tension structures", Struc. Engrge., Vol. 48, No. 2, pp. 45-54., Februrary (1970).

5. **Buchholdt, H. A.,** "A nonlinear deformation theory applied to two dimensional pretension cable assemblies " Proc. Inst. CIF. Engrs., Vol. 42, pp.129-141, 1969.

6. **Stefanou, G. D., Moossavi, E., Bishop, S., and Koliopoulos, P.,** " Conjugate gradients for calculating the response of large cable nets to static loads " Computers & Structures, Vol. 49, No.5, pp. 843-848, 1993.

7. **Stefanou, G. D., and Nejad, S. E. M.,**" Conjugate gradients for calculating the response of large cable nets to static loads " Computers & Structures, Vol. 49, No.5, pp. 843-848, 1993.

8. **Daneshjoo, F.** "Nonlinear Static Analysis of Cable Structures by Minimization of Total Potential Energy Including Instability Effects", ScientiaIranica, Vol. 6, Nos. 3 & 4, PP 233-238, 1999.

9. **Chakrabarti, S.K.**: "Handbook of offshore engineering",Planfield, Illinois, USA, 2005

10. **Det Norske Veritas.**" Enviromental Conditions and Enviromental Loads", offshore standards DNV-RP-C205, April 2007.

11. **Sarpkaya, T and Isaacson, M.** Mechanics of Wave Forces on Offshore Structures. New York: Van Nostrand Reinhold, 1981.

12. **Det Norske Veritas.** “Position mooring”, Offshore Standard DNV-OS-E301,65 Pages, June 2001.

**Table (1): Geometric properties of the petrol platform members**

| Deck members properties | | | | | | |
|---|---|---|---|---|---|---|
| Member type | External diameter D(in) | Thickness of wall t(in) | $A(m^2)$ | $J(m^4)$ | $I_y(m^4)$ | $I_z(m^4)$ |
| Vertical | 18 | 0.5 | 0.017734 | 0.0008767 | 0.0004384 | 0.0004384 |
| Horizontal* | | | 0.043232 | 0.0000115 | 0.0061708 | 0.00039* |
| Diagonal | 18 | 0.75 | 0.026222 | 0.0012609 | 0.0006304 | 0.0006304 |
| **Jacket members properties** | | | | | | |
| Member type | External diameter D(in) | Thickness of wall t(in) | $A(m^2)$ | $J(m^4)$ | $I_y(m^4)$ | $I_z(m^4)$ |
| Vertical | 48 | 1.25 | 0.1184 | 0.04178207 | 0.0208910 | 0.0208910 |
| Horizontal | 24 | 0.5 | 0.0238 | 0.00212224 | 0.0010611 | 0.0010611 |
| Diagonal | 26 | 0.5 | 0.0258 | 0.00271133 | 0.0013557 | 0.0013557 |
| Inner horizontal | 10.75 | 0.375 | 0.0079 | 0.00013708 | 0.0000685 | 0.0000685 |
| **The last three levels members properties of the jacket** | | | | | | |
| Member type | External diameter D(in) | Thickness of wall t(in) | $A(m^2)$ | $J(m^4)$ | $I_y(m^4)$ | $I_z(m^4)$ |
| Vertical | 48 | 1.5 | 0.1413 | 0.04935447 | 0.0246772 | 0.0246772 |
| Horizontal | 38 | 1 | 0.0749 | 0.01657094 | 0.0082855 | 0.0082855 |
| Diagonal | 36 | 1.5 | 0.1049 | 0.02017406 | 0.0100870 | 0.0100870 |

*I- section type which has dimensions 911.4×418.5×32×19.4mms.

**Table (2): The maximum displacements in X-and Y-direction in meters for various joints and various stations (without thrust forces)**

| Joint No. | Maximum displacement in X-direction | Station No. | Maximum displacement in Y-direction | Station No. |
|---|---|---|---|---|
| 1 | 0.009244 | 104 | 0.00066 | 99 |
| 12 | 0.008549 | 104 | 0.0005772 | 99 |
| 17 | 0.009824 | 104 | 0.000477 | 99 |
| 142 | 0.009347 | 104 | -0.00031 | 99 |
| 428 | 0.001413478 | 103 | 0.000033 | 104 |
| 271 | 0.0055 | 108 | -0.00116 | 109 |

**Table (3): The maximum internal forces (normal and moments about principal axes) for various elements and various stations**

| Element No. | Normal (t) | Station No. | Moment about major axis (m.t) | Station No. | Moment about minor axis (m.t) | Station No. |
|---|---|---|---|---|---|---|
| 882 | 7.4213 | 104 | -150.352 | 188 | 2.01644 | 186 |
| 921 | -5.9668 | 104 | -370.250 | 104 | 2.4516 | 104 |
| 2346 | 1.0259 | 104 | 72.9251 | 104 | 0.1269 | 104 |
| 4716 | -0.8401 | 104 | -123.727 | 104 | 0.364446 | 189 |

**Table (4): The maximum displacements in X-and Y-direction in meters for various joints and various stations (with thrust forces)**

| Joint No. | Maximum displacement in X-direction | Station No. | Maximum displacement in Y-direction | Station No. |
|---|---|---|---|---|
| 1 | 0.2867176 | 89 | 0.1958005 | 93 |
| 12 | 0.2586532 | 89 | 0.1954901 | 93 |
| 17 | 0.2563353 | 89 | 0.09043735 | 90 |
| 142 | 0.2522928 | 89 | 0.007907956 | 81 |
| 271 | 0.09768165 | 82 | 0.1001386 | 92 |
| 420 | 0.1481475 | 86 | 0.0965537 | 93 |
| 428 | 0.03476074 | 83 | 0.03535978 | 95 |
| 576 | 0.08087658 | 83 | 0.0531167 | 97 |
| 144 | 0.2238325 | 83 | 0.1920674 | 93 |
| 262 | 0.2156661 | 83 | 0.1646088 | 92 |
| 492 | 0.1971699 | 83 | 0.04727674 | 89 |
| 645 | 0.1756508 | 83 | -0.01643333 | 134 |
| 253 | 0.1060873 | 86 | 0.08934022 | 92 |
| 149 | 0.2240347 | 83 | 0.08805144 | 90 |
| 378 | 0.2246678 | 87 | 0.1227046 | 91 |

**Table (5): The maximum internal forces (normal and moments about principal axes) for various elements and various stations**

| Element No. | Normal (t) | Station No. | Moment about major axis (m.t) | Station No. | Moment about minor axis (m.t) | Station No. |
|---|---|---|---|---|---|---|
| 23 | 9.5674 | 175 | -0.71738 | 95 | 0.1008 | 91 |
| 124 | -119.2451 | 95 | -28.257 | 96 | 3.0795 | 102 |
| 575 | -489.37 | 90 | 1.4093 | 86 | 0.1207 | 88 |
| 633 | 446.286 | 89 | -1.41466 | 89 | 0.5797 | 102 |
| 817 | 879.3739 | 83 | -18.569 | 83 | -18.608 | 119 |
| 841 | 2339.941 | 86 | -40.13 | 74 | 108.8713 | 91 |
| 882 | 523.5977 | 90 | 147.687 | 92 | -38.4138 | 94 |
| 908 | 271.665 | 82 | 12.061 | 84 | -1.748 | 68 |
| 921 | -1832.348 | 89 | -75.404 | 86 | -4.434 | 141 |
| 980 | 1123.666 | 86 | -26.081 | 83 | -4.873 | 148 |
| 1000 | 1675.002 | 89 | -40.176 | 91 | -16.612 | 132 |
| 1098 | -433.22 | 91 | -123.421 | 92 | 32.781 | 91 |
| 1206 | 809.597 | 81 | -33.3148 | 74 | 113.988 | 93 |
| 1220 | 2127.983 | 83 | -28.293 | 65 | 109.162 | 91 |
| 2111 | -101.7204 | 94 | 0.17712 | 103 | 1.6652 | 95 |
| 2335 | -42.3157 | 102 | 0.1609 | 88 | 1.4911 | 108 |
| 2343 | -20.23 | 131 | -0.085 | 124 | 1.5948 | 99 |
| 2346 | 182.18 | 83 | 3.405 | 89 | 3.8391 | 89 |
| 4608 | 28.754 | 182 | -0.1279 | 41 | -1.601 | 68 |
| 4716 | -804.9 | 90 | -18.743 | 86 | 19.557 | 92 |

* Negative sign in normal force means compressive force and in moment mean the opposite considered direction.

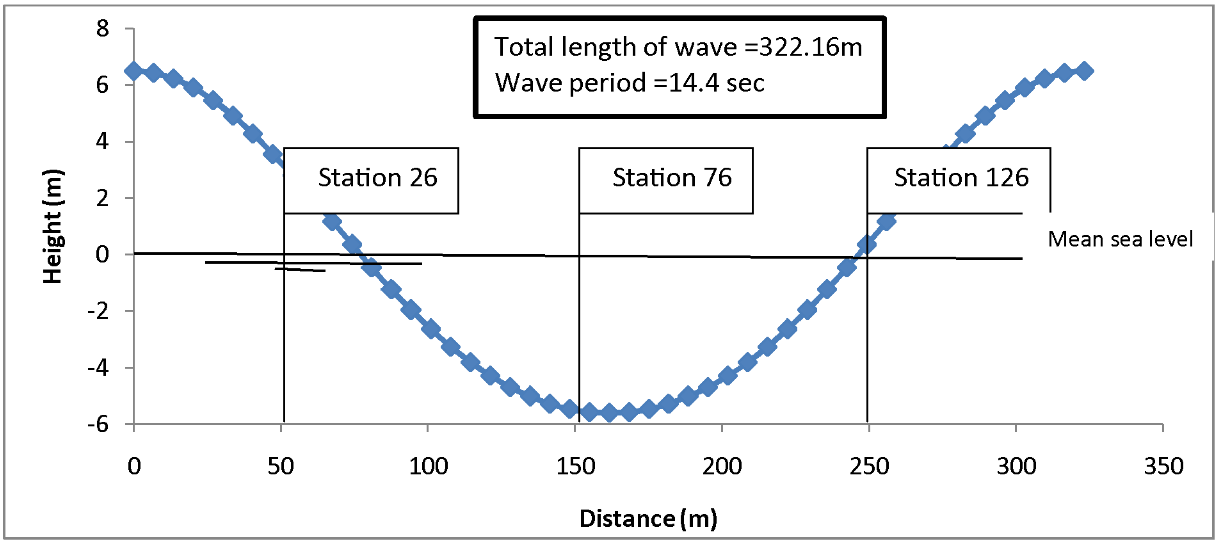



Fig. (1): Station technique

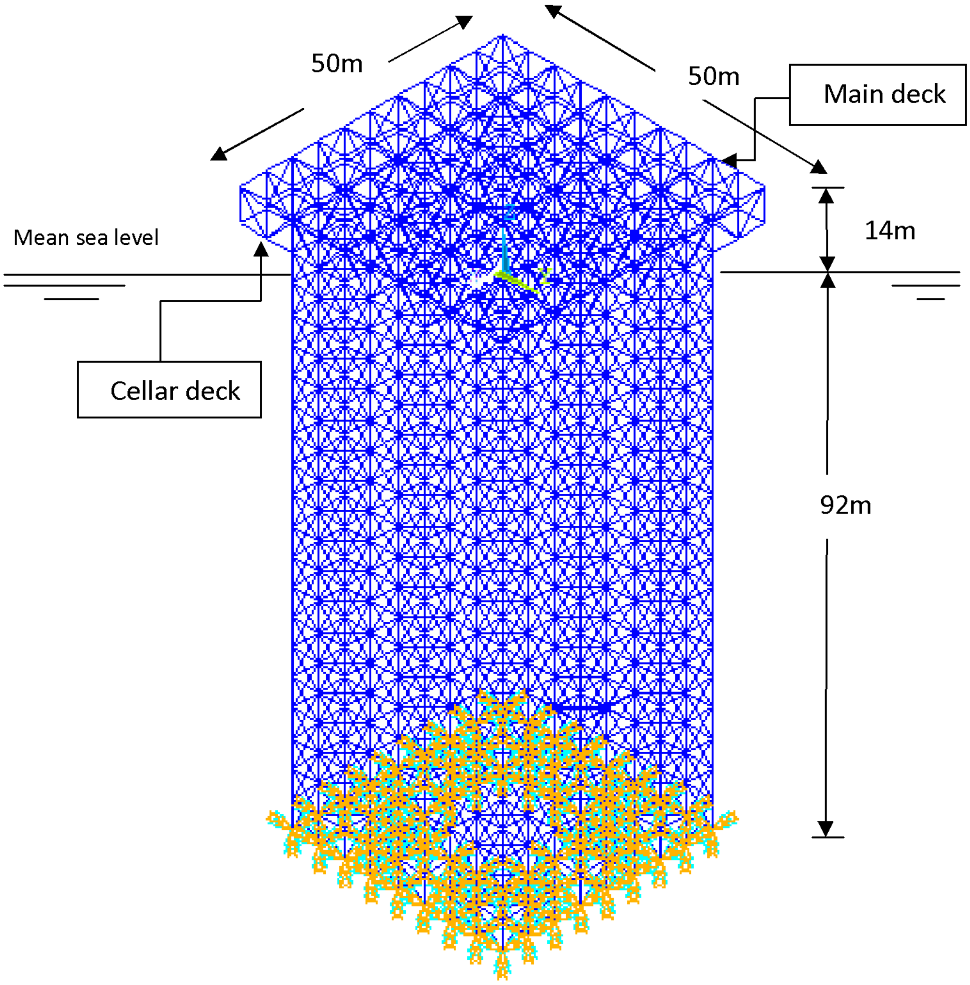
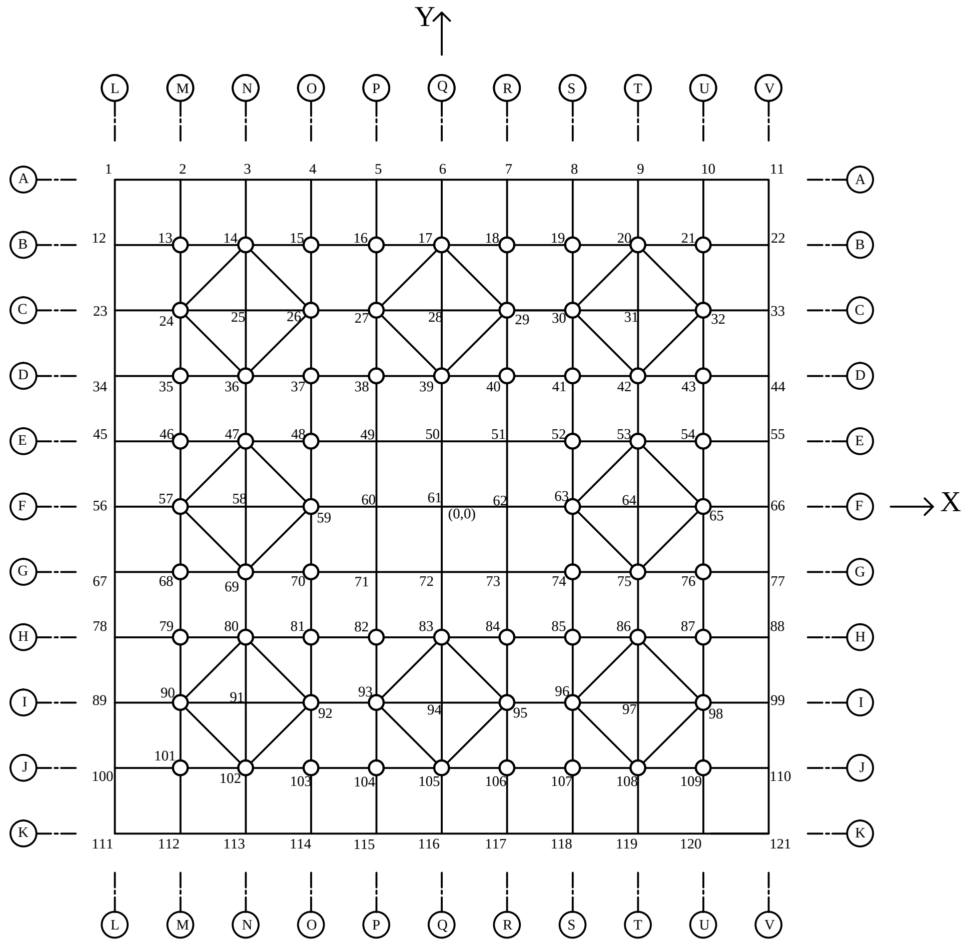
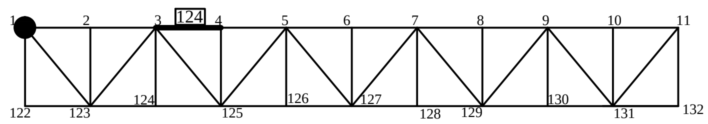


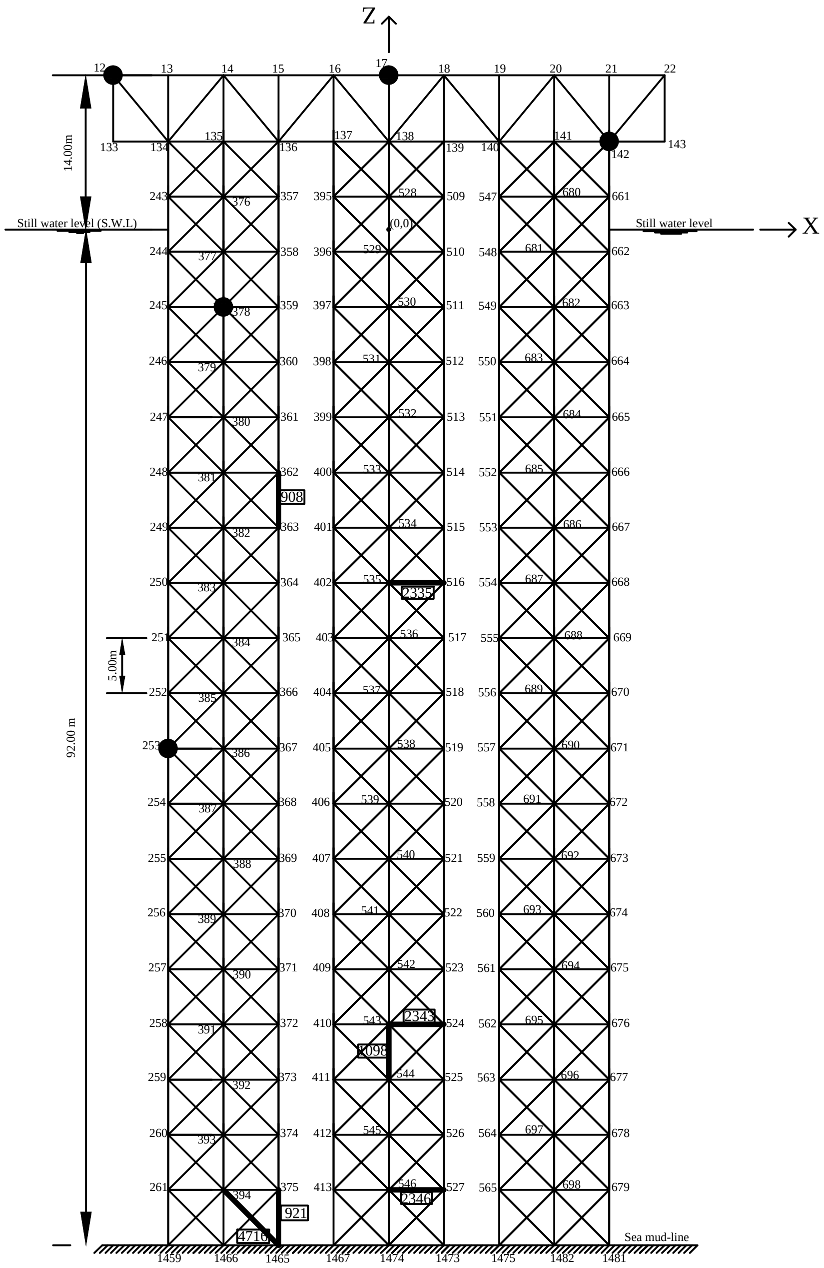

Fig. (2): Isometric view of the platform



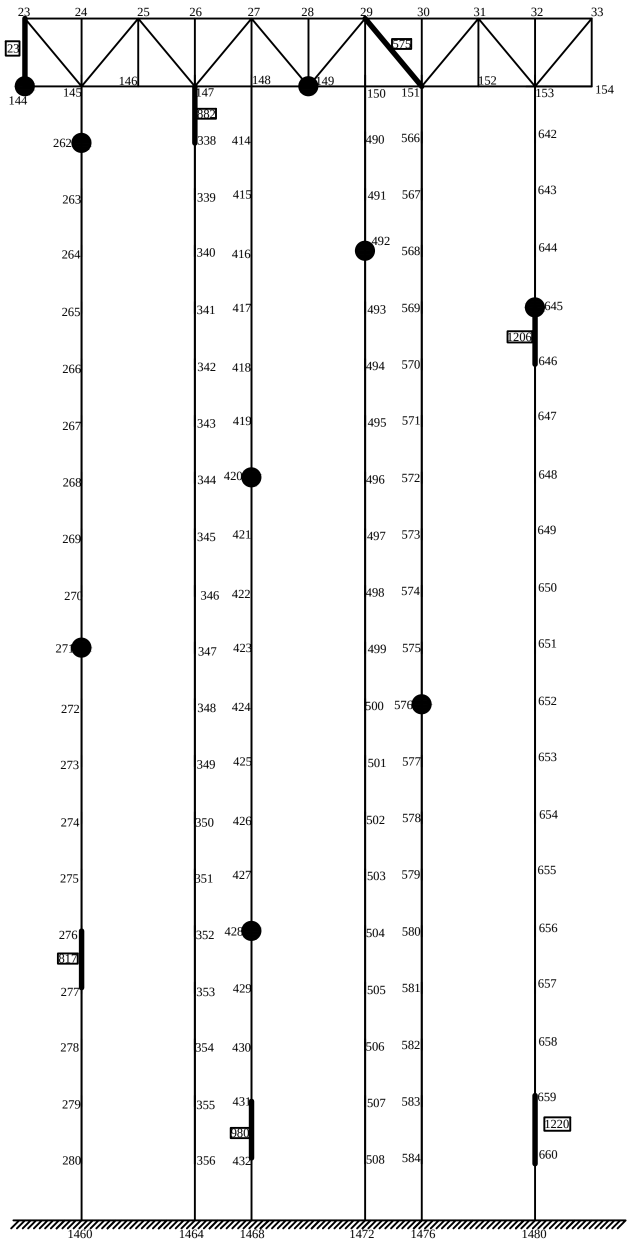

Main deck



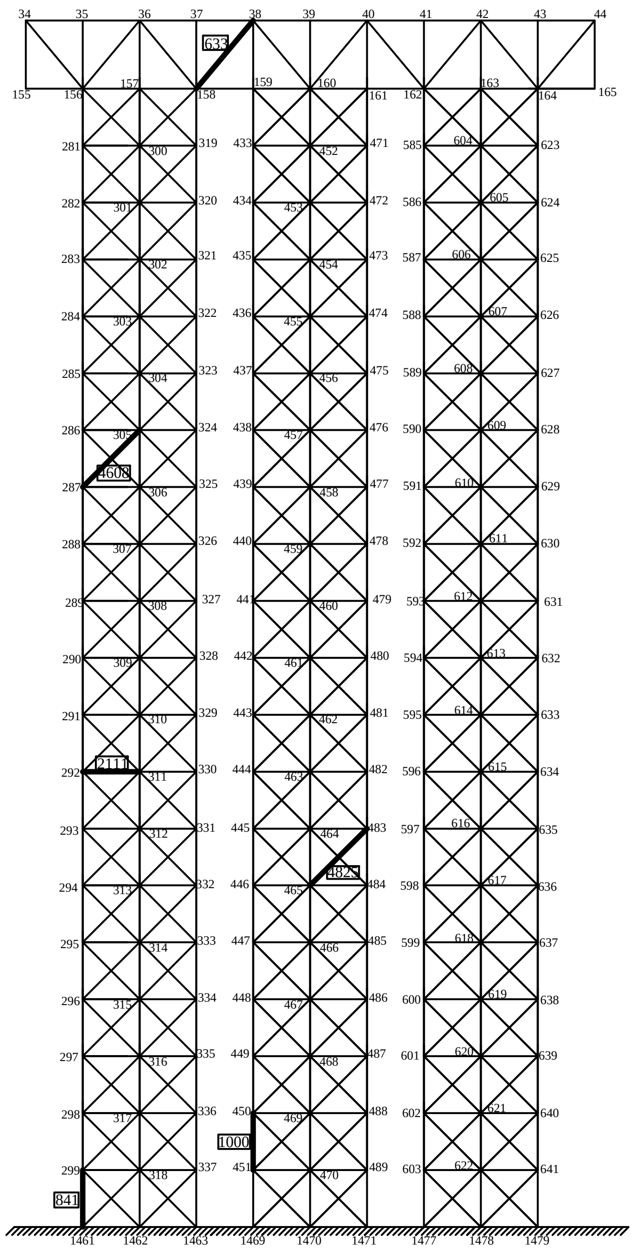
Elevation (A-A)




Elevation (B-B)



Elevation(C-C)



Elevation (D-D)

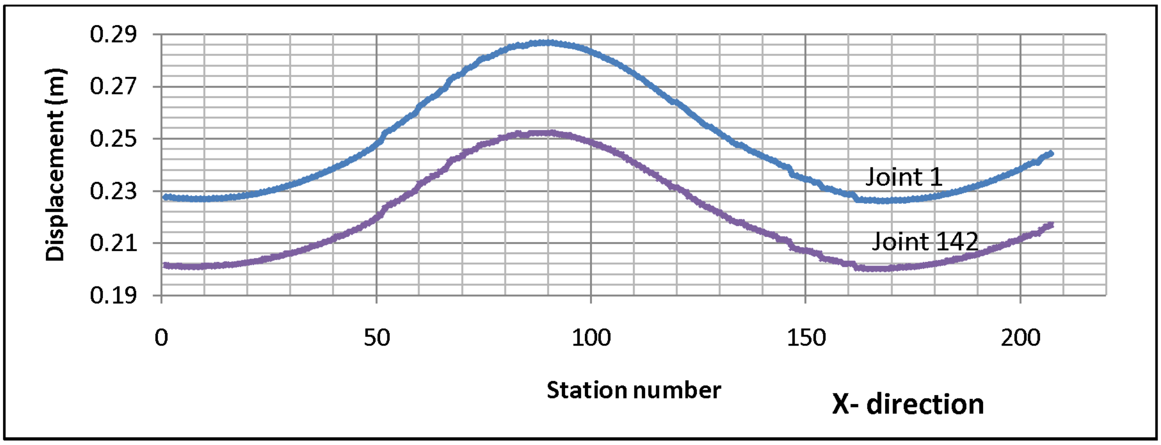



Fig. (4-a):Variations of displacements due to extreme case at various stations.

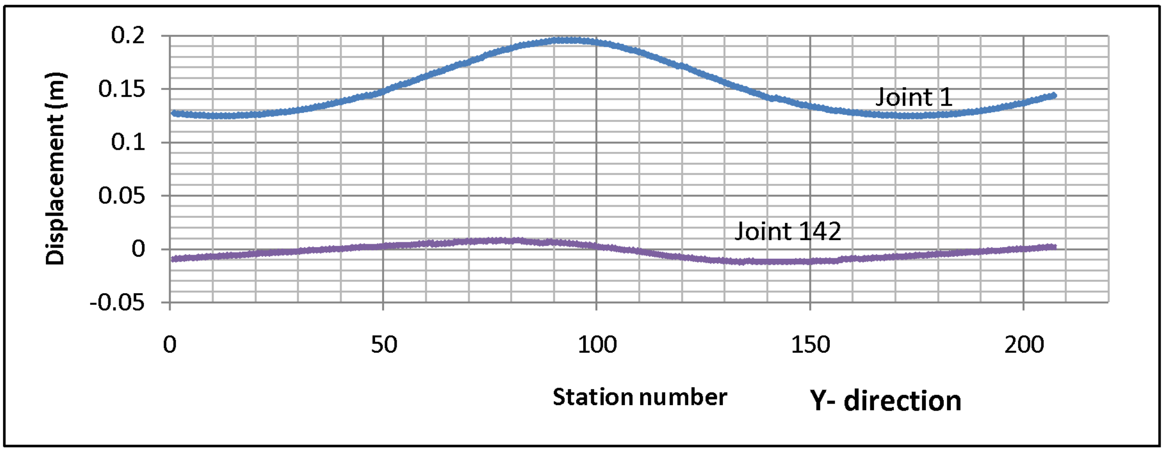



Fig. (4-b):Variations of displacements due to extreme case at various stations.

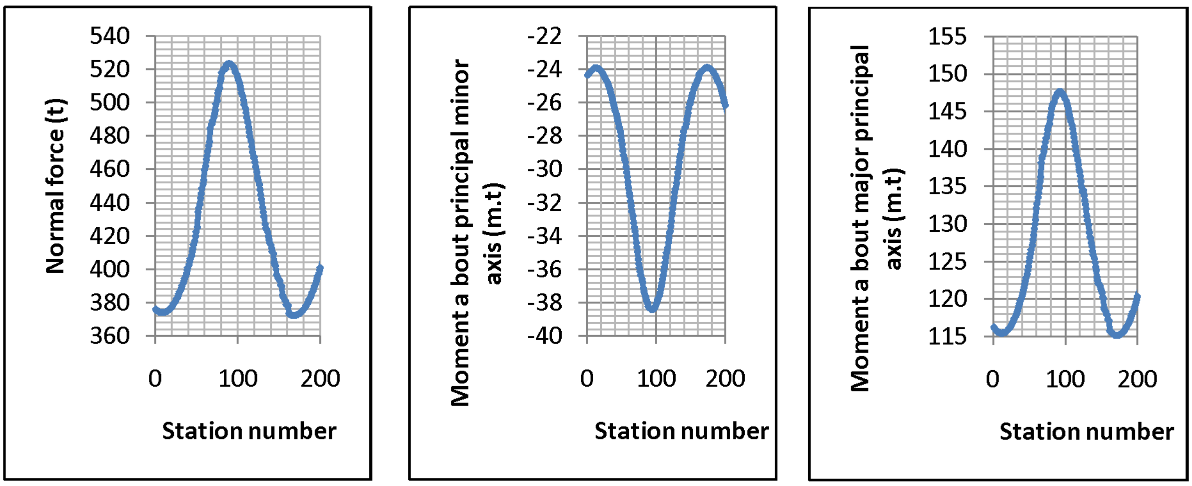



Fig. (5-a): Variations of normal force, and moments about principal axes inelement no. 882 due to extreme case.

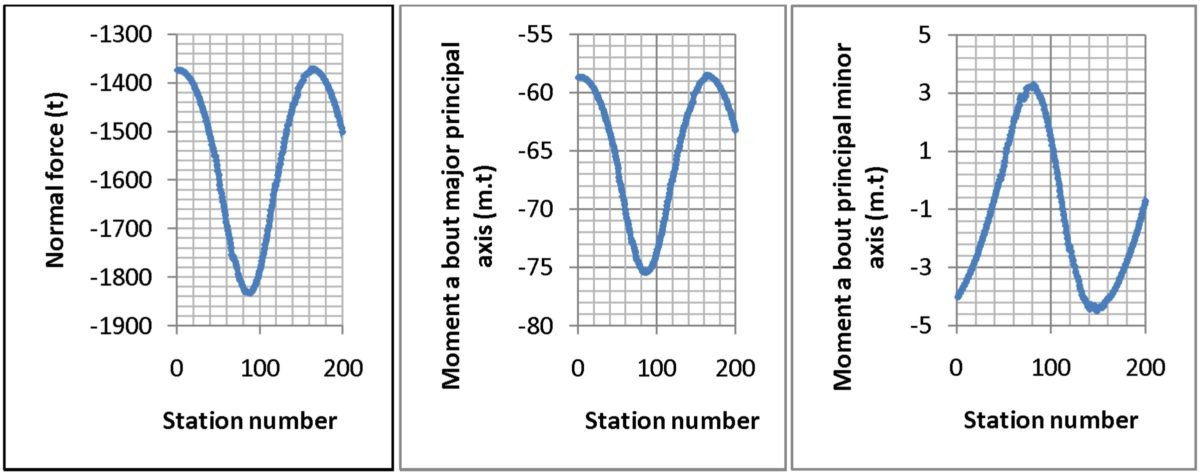



Fig. (5-b): Variation of normal force, and moments about principal axes in element no. 921 due to extreme case.

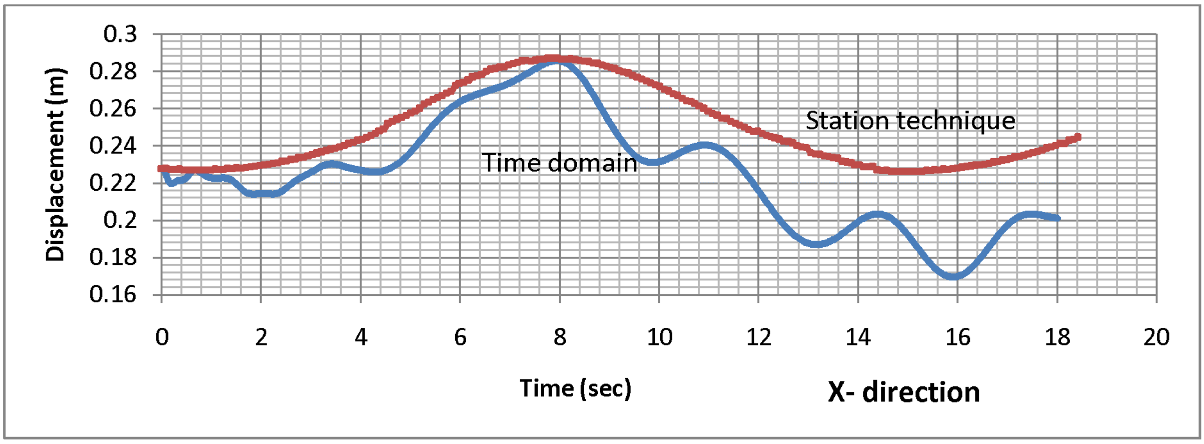



Fig. (6-a): Variations of displacements using load station technique and time domain technique at joint no.1.

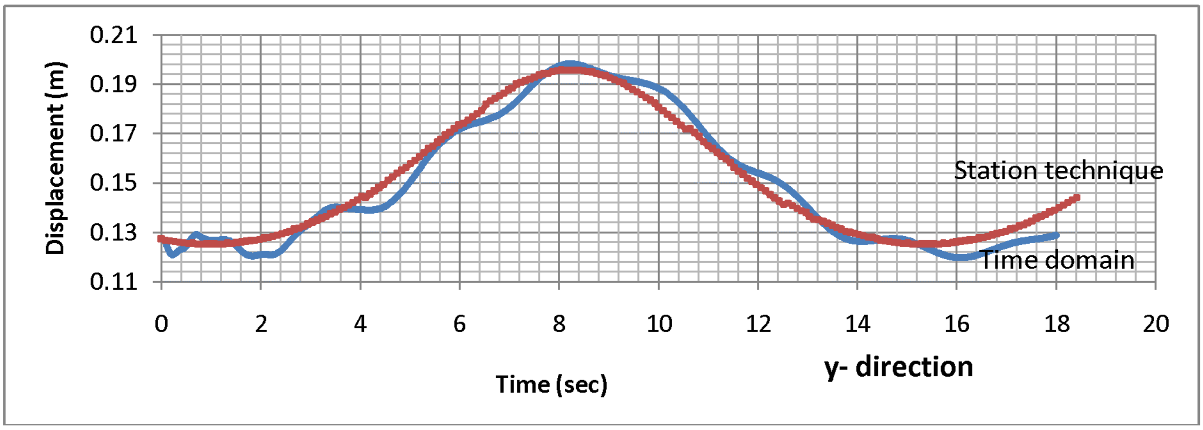



Fig. (6-b): Variations of displacements using load station technique and time domain technique at joint no.1.

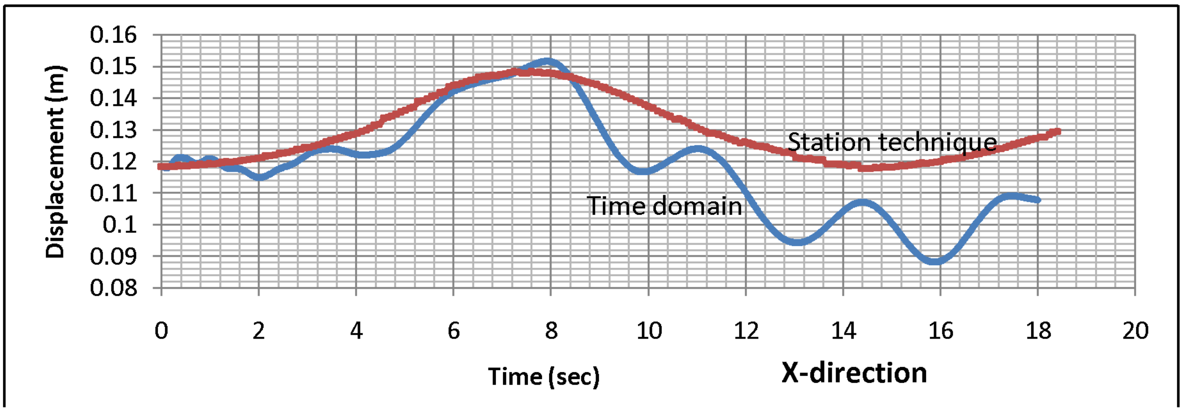



Fig. (6-c): Variations of displacements using load station technique and time domain technique at joint no.420.

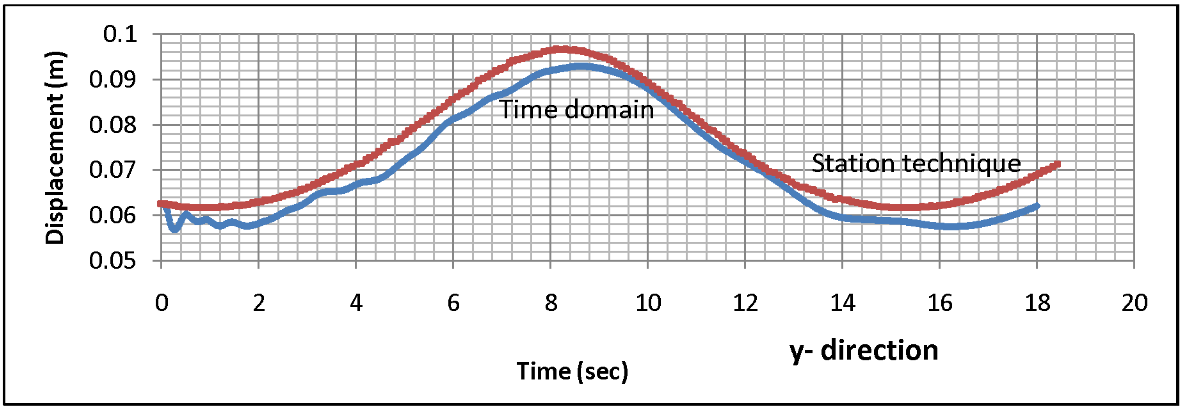



Fig. (6-d): Variations of displacements using load station technique and time domain technique at joint no.420.

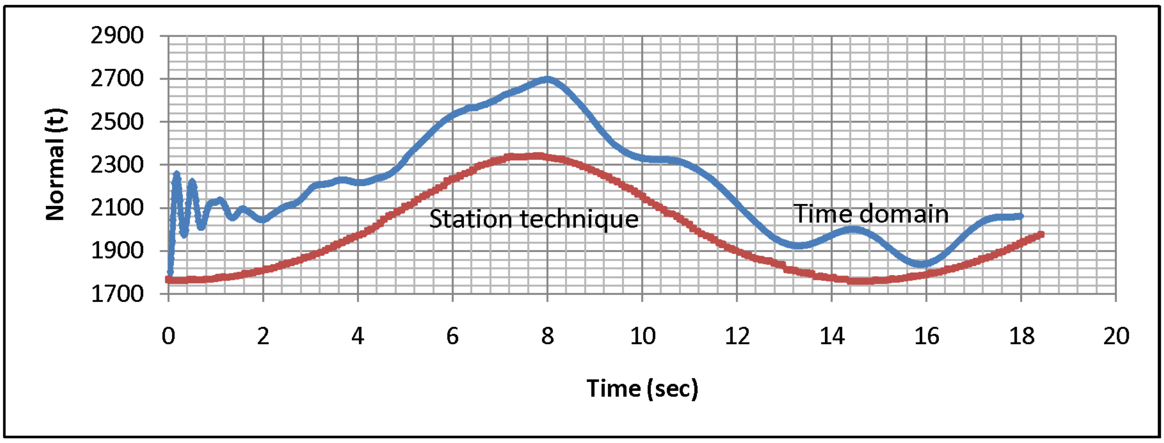



Fig. (7-a): Variations of normal forces using time domain technique and dynamic load stations technique for element no. 841.

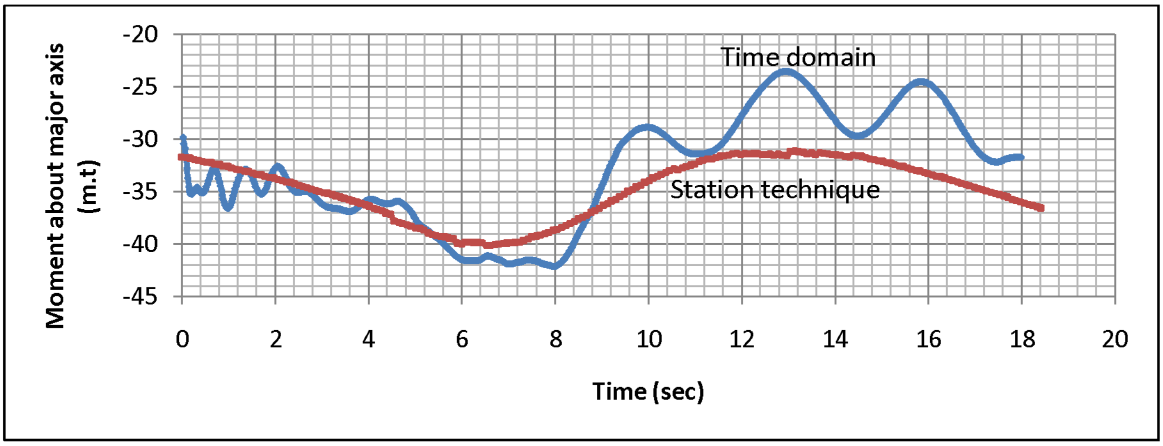



Fig. (7-b): Variations of moments about major principal axis using time domain technique and dynamic load stations technique for element no. 841.

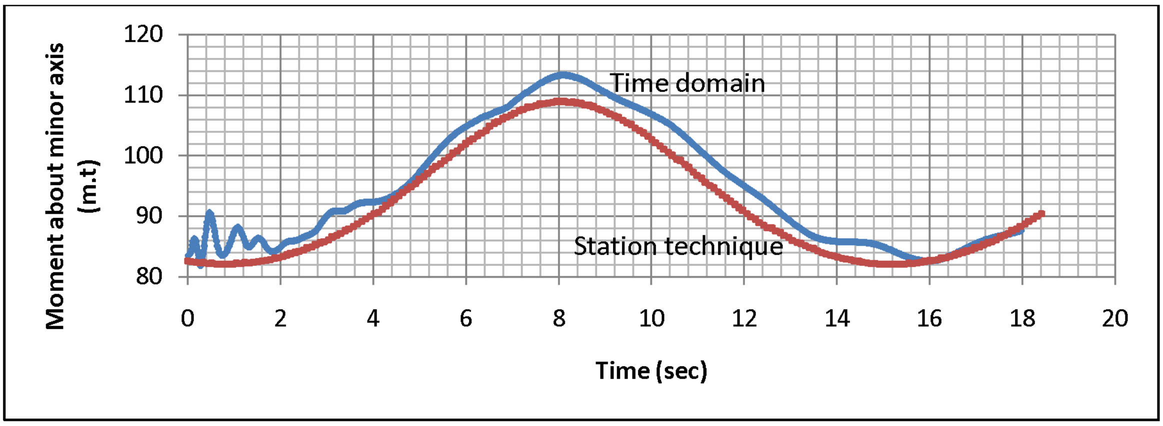



Fig. (7-c): Variations of moments about minor principal axis using time domain technique and dynamic load stations technique for element no. 841.

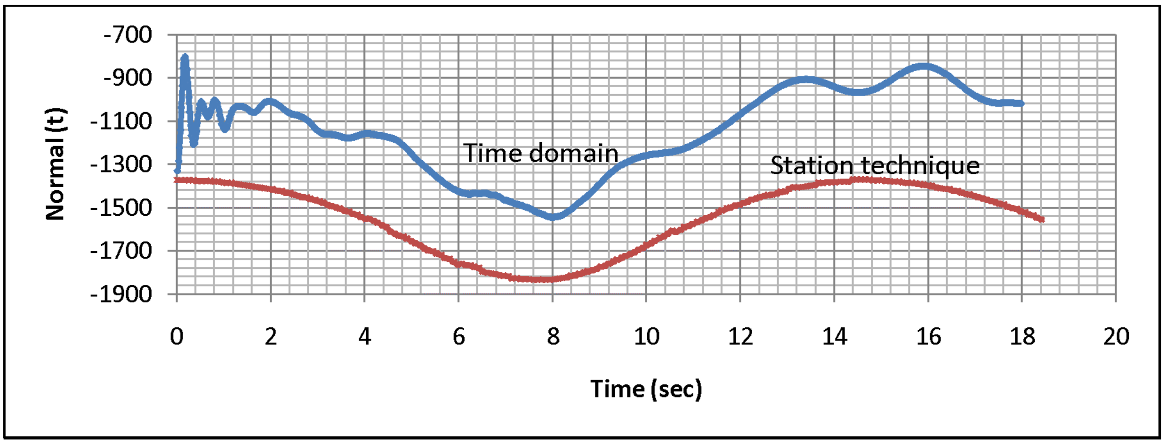



Fig. (7-d): Variations of normal forces using time domain technique and dynamic load stations technique for element no. 921.

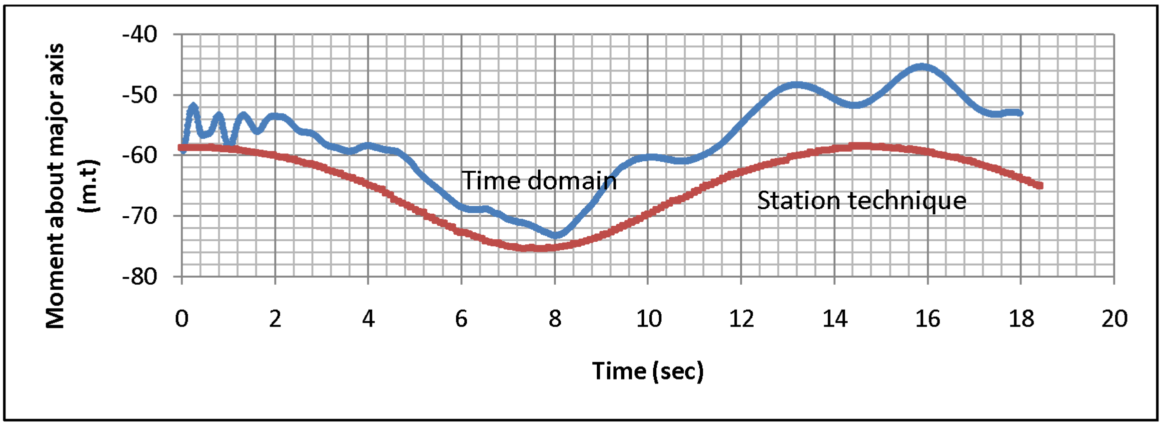



Fig. (7-e): Variations of moments about major principal axis using time domain technique and dynamic load stations technique for element no. 921.

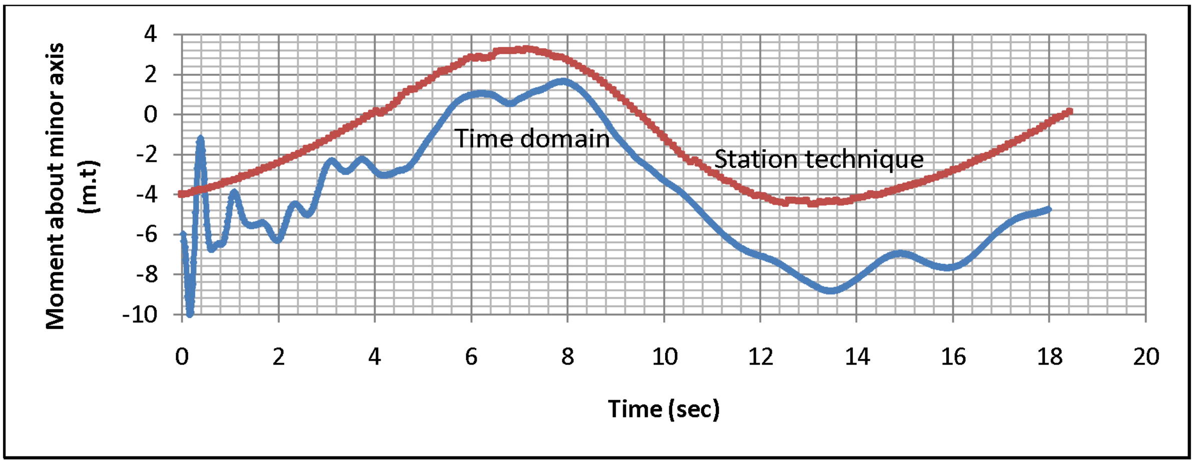



Fig. (7-f): Variations of moments about minor principal axis using time domain technique and dynamic load stations technique for element no. 841.