EFFECT OF INITIAL SAG AND TENSION IN CABLES ON OUTCOME RESPONSES IN CABLE STRUCTURES

By

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تأثيرالارتخاء والشد الابتدائيين بالكابلات على الاستجابات الناتجة في المنشاءات الكابولية.

الخلاصة: إن الهدف الرئيسي لهذا البحث يتركز في دراسة تأثير كل من الارتخاء الابتدائي والشد الابتدائي في الكابلات خاصة الكابلات المائلة على كل ا من التحليل الاستاتيكى والديناميكي لبعض المنشاءات الكابولية مثـــل الكباري ذات الدعامات الكابولية والأبراج الملجمة وذلك بإتباع تقنية جديدة في دراسة تأثير الشد الابتـــدائي فـــي الكابلات تعتمد على دورات متكررة في إجراء التحليل الاستاتيكى للوصول إلى الشد الابتدائي الامثل المصاحب لأقل ناتج فى الاستجابات الاستاتيكية المختلفة وقد تمت الدراسة بإجراء التحليل الاستاتيكى علـــى الكبـــاري ذات الثلاث بحور مصحوبة بأربعة أنواع من الوصلات الشائعة الاستخدام بين الأبراج وكمرات أسطح هذة الكبـــاري مع فرض حالتين من التحميل تمثل الأحمال المتماثلة وغيرا لمتماثلة بالكباري وكذلك تم دراسة الأبراج الملجمـــة أخذا في الاعتبار أحمال الرياح ذات السرعات العالية في ثلاث اتجاهات حرجة وذلك على التحليل الاستاتيكى والديناميكي لهذة الأبراج باستخدام طريقة الطاقة المبنية على تصغير طاقة الوضع باستخدام الانحدارات المتبادلة وأخذا في الاعتبار اللاخطية في سلوك التشكل الهندسي للمنشأ وكذلك نوع المواد المستخدمة في الإنشاء وقد قام الباحث بإنشاء جميع البرامج المستخدمة مع التأكد من إعطائها نتائج ذات وثوقية عالية مقارنة بحـــزم البـــرامج الجاهزة في هذا المجال وفى النهاية تم تدويـــ وذكـــر أهـــم النتائج وتحليلها إحصائيا للوصول إلى أفضلها والتي تمثل تخفيض عالي لناتج الاستجابات الاستاتيكية والديناميكية.

Abstract

The main object of this research is concerned about the effect of both initial sag and initial tension in inclined cables on the outcome responses of some cable structures , such as cable stayed bridges and guyed towers. A new technique for the choice of the best initial tension in cables depending on an iterative scheme to give the minimum static responses. This technique is termed " optimum outcome response shape'. The static analysis of cable stayed bridges having three spans with single cables in harp, radiating and fan shapes, which represent the most common bridges, and guyed towers, is carried out. Two cases of loading which include the most dominant symmetric and asymmetric traffic loads with four cases of connections types between pylons and floor beams are considered in the analysis of the bridges. Also , the case of wind load with mean wind speed of 150 km/hour at 10 m, above the ground is considered for guyed towers . Both static and dynamic analyses are carried out taking into consideration geometric and material nonlinearities. In both static and dynamic analyses, the energy method, based on the minimization of the total potential energy of structural elements, via conjugate gradient technique is used. The procedure is carried out using iterative steps to acquire the final configurations. All prepared computer programs in FORTRAN language for this work are written by the author which programs have a high reliability when compared with other prepared programs in this field. The major conclusions which give a significant reduction in the outcome responses, have been drawn ..

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1- Introduction

The most advanced investigations in structural engineering have mainly been carried out in the field of cable structures. Cable stayed and suspension bridges, cable roofs and guyed towers have a wide field of applications. During the past few decades ,cable-stayed bridges have found wide applications in the world especially in Western Europe. The development of communication means has resulted in a demand for very tall structures (guyed towers) to carry the radiating antennae. The development and application of electronic computers and the unlimited possibilities of the solutions of these structures gave the ability of much knowledge in this field. The most common cable- stayed bridges may be classified as harp, radiating and fan depending on the arrangements of cables and their connections with the pylons. The own weight of all bridge elements with all various cases of equivalent traffic loads including impact on the girders are considered. A single plane of cables is considered as the mathematical model in the analysis of the bridges. The primary loads on guyed towers are due to dead weight of the structural members, the weight of supported equipment, insulators, any other associated apparatuses, and wind loads. The loads due to wind are greatly affected by the shape and orientation of the tower to the direction of the wind, the ratio of the solid area to the total enclosed area of a vertical face (solidity ratio) and the cross-sectional shape of the individual members of the tower. In both cable- stayed bridges and guyed towers, the analysis is carried out considering cable and space frame elements for cables and pylons, floor beams and mast , respectively.

A non- linear response theory based on minimization of the total work with particular reference to the use of the conjugate gradient method is presented. The summary of the iterative scheme with optimum outcome responses shape technique is presented. The dynamic theory used for the dynamic analysis in this paper is based upon step by step response calculation in the time domain, for which equilibrium of the forces at the end of each time step is established by minimization of the total potential work, using the same method of conjugate gradient. In both static and dynamic iterations, the Euclidean norm of the gradient vector or unbalanced force vector is taken as 0.01% and 0.1 % , respectively. Main sources of knowledge about this method are given in[1, 2, 3, 4, 5, 6, 7, and 8]. Many numerical examples were presented to illustrate the new technique (optimum outcome responses shape) to get the best initial tensions in cables that satisfy minimum outcome responses in cable structure. Finally, the major conclusions are presented.

2.Freely hanging cable under uniformly distributed loading [1]

The analysis of single cable either as catenary , parabola, or as a straight element under uniformly distributed load or concentrated loads was presented by [9]. A mathematical representation of cable stress-strain curves is proposed in [10]. The final cable length for a cable having small sag/span ratio is computed using the shear –volume method by [11]. The governing equation for a freely suspended parabolic cable under several types of distributed load along the cable span is mentioned in [1]. This equation with reference to Fig(1), is:

$$H\frac{\partial^2 z}{\partial^2 x} + w_x = 0 \qquad (1)$$

Where: H = The horizontal component of the tension in the cable;

w_x = The uniformly distributed load along the cable span; and

x and z = The horizontal and vertical coordinates of a point along the cable, respectively .

By integrating the above equation twice and for boundary conditions ($z=0$ at $x=0$ and $z=Z$ at $x=X$):

$$\therefore\ Hz = \frac{1}{2} w\,(Lx-x^2)+H\,\frac{Z}{L}x \qquad (2)$$

$$z = \frac{w}{2H}[Lx - x^2] + \frac{Z}{L}x \qquad (3)$$

∴ The position of maximum sag, d, occurs at the mid-span, ($x = L/2$)

Substituting $x = \frac{L}{2}$ at $z = d$ in eqn. (2) yields:

$$H = \frac{wL^2}{8d} \qquad (4)$$

Finally, substituting the expression for H in eqn. (2) yields:

$$z = \frac{4d}{L^2}(Lx - x^2) + x\frac{Z}{L} \qquad (5)$$

Eqn. (5) shows that the cable shape is parabolic when the load is uniformly distributed across the span rather than along the cable itself. The length of the cable can be expressed as:

$$l = \int_0^L \sqrt{1 + (\frac{dz}{dx})^2}\,dx \qquad (6)$$

Expanding the square root in eqn. (6) by the binomial theorem, including the first three terms only and by integrating between limits, yields the following expression for the cable length:

$$l = L\{1 + \frac{8}{3}(\frac{d}{L})^2 - \frac{32}{5}(\frac{d}{L})^4 + \frac{1}{2}(\frac{Z}{L})^2 - \frac{1}{8}(\frac{Z}{L})^4 - \frac{4}{3}(\frac{d}{L})^2(\frac{Z}{L})^2\} \qquad (7)$$

Considering $f = d/L$ (8)

The tensions at the ends of the cables are:

$$T_A = H\sqrt{1 + (\frac{Z}{L} + 4f)^2} \qquad (9)$$

$$T_B = H\sqrt{1 + (\frac{Z}{L} - 4f)^2} \qquad (10)$$

In this method, the cable segment is divided into several elements. Within each element the uniform load, area, and modulus of elasticity will be assumed invariable. A new element will begin at each discontinuity of load, area, or modulus of elasticity or at applying vertical or horizontal loads.

3. Summary of an optimum outcome responses shape technique

An optimum outcome responses shape has to be carried out in order to reduce the deflection and to smooth the bending moments along floor beam , sway along pylon in cable-stayed bridges and sway and bending moment along shaft in guyed towers. In all cases, the initial tensions in cables are taken as 10 % of minimum ultimate values. Then, a new equilibrium configuration under the action of dead load and equivalent live loads in case of cable-stayed bridges and maximum wind loads in case of guyed towers and cable initial forces will be determined again during an optimum outcome responses shape. Several control points(nodes intersected by the girder, pylons, shafts, and cables) will be chosen for checking if the convergence tolerance is achieved or not [12].

The main steps in optimum outcome responses shape technique through the iterative processes required to achieve structural equilibrium by minimization of the total potential energy may be summarized as follows.

I-Consider in the first cycle an initial tension in all cable members as a 10% of the minimum ultimate value , T_u, then:

II-First, before the start of the iteration scheme

a) Calculate the tension coefficients for the pretension forces in the cables by.

$$t_{jn} = \left[\left(T_0 + \frac{EA}{L_0}e\right)/L_0\right]_{jn} \qquad (11)$$

Where: t_{jn} = the tension coefficient of the force in member jn ;

e =elongation of cables due to applied load,

T_0 = initial force in a pin-jointed member or cable link due to pretension;

E = modules of elasticity;

A = area of the cable element, and

L_0 = the unstrained initial length of the cable link.

b) Assume the elements in the initial displacement vector to be zero.

c) Calculate the lengths of all the elements in the pretension structure using the following equation:

$$L_0^2 = \sum_{i=1}^{3} \left(X_m - X_p \right)^2 \qquad (12)$$

Where: X = element in displacement vector due to applied load only, and

d) If either the method of steepest descent or the method of conjugate gradients is used, calculate the elements in the scaling matrix, [13, 14 ,and 6] :

$$H = diag\left\{ k_{11}^{-1/2}, k_{22}^{-1/2}, \ldots\ldots\ldots\ldots k_{nn}^{-1/2} \right\} \qquad (13)$$

Where: n = total number of degrees of freedom of all joints, and

k = the 12 x 12 matrix of the element in global coordinates.

III- *The steps in the iterative procedure are then summarized as:*

Step (1) Calculate the elements in the gradient vector of the *TPE*, using:

$$g_m = \sum_{n=1}^{f_n} \sum_{r=1}^{12} \left(k_{nr} x_r \right)_n - \sum_{n=1}^{pn} t_{jn} (X_m + x_m - X_p - x_p) - F_m \qquad (14)$$

Step (2) Calculate the Euclidean norm of the gradient vector, $R_k = \left[g_k^T g_k \right]^{1/2}$, and check if the problem has converged. If $R_k \le R_{\min}$ stop the calculations and print the results. If not, proceed to step (3).

Step (3) Calculate the elements in the descent vector, v using:

$$[v]_{k+1} = -[H][g]_{k+1} + \beta_K [v]_k \qquad (15)$$

Where $\quad [v]_0 = -[g]_0 \qquad (16),$

and

$$\beta_k = \frac{[g]_{k+1}^T [H]^T [H][g]_{k+1}}{[g]_k^T [H]^T [H][g]_k} = \frac{[g]_{k+1}^T \left[\hat{K} \right] [g]_{k+1}}{[g]_k^T \left[\hat{K} \right] [g]_k} \qquad (17)$$

Step (4) Calculate the coefficients in the step-length polynomial from:

$$C_4 = \sum_{n=1}^{P} \left(EAa_3^2 / 2L_0^3 \right)_n \qquad (18\text{-a})$$

$$C_3 = \sum_{n=1}^{P} \left(EAa_2 a_3 / L_0^3 \right)_n \qquad (18\text{-b})$$

$$C_2 = \sum_{n=1}^{P} \left[t_0 a_3 + EA\left(a_2^2 + 2a_1 a_3 \right) / 2L_0^3 \right]_n + \sum_{n=1}^{f} \sum_{s=1}^{12} \sum_{r=1}^{12} \left(\frac{1}{2} v_s k_{sr} v_r \right)_n \qquad (18\text{-c})$$

$$C_1 = \sum_{n=1}^{P} \left[t_0 a_2 + EAa_1 a_2 / L_0^3 \right]_n + \sum_{n=1}^{f} \sum_{s=1}^{12} \sum_{r=1}^{12} \left(x_s k_{sr} v_s \right)_n - \sum_{n=1}^{N} F_n v_n \qquad (18\text{-d})$$

Where:

$$a_1 = \sum_{i=1}^{3} \left[\left(X_m - X_p \right) + \frac{1}{2} \left(x_m - x_p \right) \right] \left(x_m - x_p \right)$$

$$a_2 = \sum_{i=1}^{3} \left[\left(X_m - X_p \right) + \left(x_m - x_p \right) \right] \left(v_m - v_p \right)$$

$$a_3 = \sum_{i=1}^{3} \frac{1}{2} \left(v_m - v_p \right)^2 \qquad (19)$$

Where:

f = number of flexural members,

P = number of pin-jointed members and cable links,

F = element in applied load vector, and

K_{sr} = Element of stiffness matrix in global coordinates of a flexural element.

Step (5) Calculate the step-length S using Newton's approximate formula as:

$$S_{k+1} = S_k - \frac{4C_4 S^3 + 3C_3 S^2 + 2C_2 S + C_1}{12C_4 S^2 + 6C_3 S + 2C_2} \qquad (20)$$

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

Step (6) Update the tension coefficients using the following equation.

$$(t_{ab})_{k+1} = (t_{ab})_k + \frac{EA}{(L_0^3)_{ab}} (a_1 + a_2 s + a_3 s^2)_{ab} \qquad (21)$$

Step (7) Update the displacement vector using equation (11).

Step (8) Repeat the above iteration by returning to step (1) , under item III.

IV– Take the final tension in cables for each group of cables as an initial tension and start again with II.

V– In each cycle of solution, the ratio of the vertical displacements in deck floor or lateral sway in pylons in cable-stayed bridges and shafts in guyed towers at control points , to those at main structural points, μ , will be checked. i.e $\mu < €$, where € is the convergence tolerance. The cycles of solutions will be repeated until the convergence tolerance is achieved .other wise continue with step **II.**

The computation by optimum outcome responses shape technique will be stopped and it is found if one of the following is responded first:

1. The initial tension in cables does not exceed 40 % of minimum ultimate values of these cables.
2 The maximum outcome responses along control points does not exceed those values recorded in the previous cycle of solution.
3. The convergence tolerance is reached.

VI- The final tensions in cables are considered as initial tensions when carrying out all required static and dynamic analyses with any other symmetric and asymmetric cases of loading. The ratio of final tension for each group of cable members to the minimum ultimate value is called £.

4. Geometry and properties of the bridges and the guyed tower.

Three span cable- stayed bridges having cables in harp ,radiating and fan shapes considering single plane of cables as shown in Fig.(2-a), Fig.(2-b), and Fig.(2-c), respectively[15] and guyed tower as shown in Fig.(2-d) are considered. Four cases of connection types between pylons and floor beams as shown in Fig.(3-a) are considered [16]. All bridges have two equal exterior spans of 140m, and an interior span of 280 m. The deck girder has a total span of 560 m. The dimensions were chosen to satisfy most factors affecting the optimum shape of the bridges [17, 18, and 19]. The bridge is symmetric and is composed of three major elements: (a) deck girder, (b) two pylons and (c) eleven cables on each side of pylon. The properties of pylon, deck floor and cables in cable-stayed bridges are given in Table(1). The guyed tower is constructed in 1959 at Dover (South East of England) for ITV network [7 and 20]. It consists of equilateral triangular section with vertical legs designed as solid tubular steel sections, and diagonal bracing of angle profiles. The mast carries 10 m cantilever and each face of the mast section is 1.98 m, wide. It is supported laterally by guys attached at five levels with three guys at each level. All the guys are made from the same type of 91-spiral strand, but with different dimensions at each guy level. The mast carries a disk at level 228.6 m with an area of 4 square meters, and weight of about 1.55 ton. Specifications for the lattice and guys in Dover guyed tower are given in Tables (2 and 3),respectively.

5. Analysis Considerations

The cable- stayed bridges are analyzed as a single plane of cables in the mathematical model. Each bridge has 1302 and 1278 degrees of freedom for both pairs of connection types (A and B)as well as (C and D), respectively. The static analysis for all cable- stayed bridges are carried out considering cases of loading (1) given in Fig. (3-b). Both static and dynamic analyses of guyed tower are made due to self weight of structural elements and wind loads , considering three different directions as mentioned in Fig.(3-c). Data for calculating drag forces in guys and lattice for Dover tower are given in Table(4). The shear velocity of wind and the roughness length are taken as 4.285 m/sec. and 0.20m. The mean wind speed at 10m, elevation above the ground is taken as 150 km/hour. The most general law describing the way in which the mean velocity varies with height, Z, is the "logarithmic law" and is given by:

$$U(z) = 2.5\, u_{*} \ln (Z/Z_o) \quad (21)$$

In which, u_{*} = the shear velocity or friction wind velocity, and

Z_o = roughness length.

6) cases study:
This part comprises the following items:

a) Effect of initial sag in cables:
First, the effect of initial tension in inclined cables using the technique mentioned in item 2 is presented. With inclined cable having 12 equal segments , 120 m lengths , for each horizontal and vertical projections and four various initial tensions , the results are tabulated and given in Table(5).
Second, the effect of initial sag in cables on the outcome responses is carried out for cable-stayed bridge in harp shape and guyed tower. Some static responses such as, variations of sway and bending moments along pylon height , and deflection and bending moment along floor beam with connection type (A) are shown in Figs.(4-a),(4-b),and (4-c), respectively. Also, the variations of sway along tower height in guyed tower are shown in Fig.(13).

b) Effect of initial tensions in cables on the outcome static responses.
1. The static analysis is carried out for cable-stayed bridges in harp shape with case of loading (1) and considering three cases of initial tensions , such as 10 % T_u , 50 % T_u and the new technique (item 3), in which T_u is the minimum ultimate tension in cables. Some of the obtained results are shown in Fig.(5).
2.The same previous assumptions are considered except for the case of 50 % T_u for radiating and fan bridges which are presented and drawn in Figs.(6) , and (7), respectively.
3. The static analysis is carried out with the best obtained initial tensions in cables using an optimum outcome responses shape having £. coefficients given in Tables (6, 7, and 8) for harp, radiating, and fan shapes, respectively. The variations of floor beam responses considering case of asymmetric loading (2) (deflection , normal forces, and bending moments) are shown in Figs.(8, 9, and 10) for harp, radiating, and fan bridges, respectively.
The variations of sway along pylon height for all bridge types are shown in Fig.(11). Finally, The bending moment, sway, and normal forces along tower height for Dover tower are shown in Fig.(12).
4. Effect of connections between pylons and floor beams :
Various studied cases are presented and summarized in Table (9).
5.To confirm all previous results obtained from static analysis, the dynamic analysis in time domain for Dover guyed tower is carried out considering wind direction (1) and properties of wind and drag forces mentioned before. The total time of dynamic analysis was taken as 30 seconds with time step of 0.02 sec. The first natural frequency for shaft was 0.288 hertz The damping was 0.02. Some obtained dynamic time histories(horizontal sway and velocity at tower top, final tension in upper cable, moment in shaft at third cable level, and normal force in shaft at its support) are shown in Fig.(15). Finally, some statistic analyses for dynamic time histories are given in Table (10).

7- Analysis of results.
It may be concluded that:
1. The initial sag of cables decreases with increasing initial tensions.
2. An increase of about 5% to 10 % for structures responses occurs when taking sagging effect into consideration.
3. An increase of initial tension without any constraints, causes a disturbing in outcome responses (Figs. 5-a, 5-b, and 5-c).
4. Using optimum outcome responses shape technique gave a significant decrease in all responses. With the case of symmetric loading, the following reduction percentages are found:
a) deflection in floor beam = 65 % to 80 %.
b) bending moment in floor beam = 50 % to 70 %.
c) normal force in floor beam is very close to the case of 10 % Tu

d) sway in pylon = 60 % to 75 %.
e) normal force in pylon is very close to the case of 10 % T_u
f) bending moment in pylon. = 50 % to 80 %.
g) the variation in tension in cables is small .

5) for the case of asymmetric loading, the use of an optimum responses shape technique had the minimum reduction factor for deflection, sway , and bending moment in floor beams. This reduction is more than 50 %, while the variations in normal forces are insignificant.

6) The results for dynamic responses confirmed the results of static responses.

8- Major conclusions:

The major conclusion that may be drawn from the present work are:
1.Effect of initial sag in inclined cables depend on the initial tensions therein and must be taken into consideration. It causes an increase of about 5-10%.
2.The initial tension in cables plays an important role in the analysis of cable structures.
3.The assessment of initial tensions in cables must be controlled with a high degree of attention.
4. An optimum outcome responses shape technique is assuredly acceptable for finding the best initial tensions in cables for all types of cable structures. It gives a very good reduction in deflections along floor beams and sway along pylons in cable stayed bridges. The bending moments along the floor beam are rather smooth .
5.The dynamic analysis confirmed the good results obtained from the static analysis.

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Table (1) : properties of pylon, deck floor and cables-stayed bridges.

Structural element	Description of structural elements	Properties of sections					loads	
		Young's modulus t/cm2	Area m^2	inertia I_x m^4	Inertia I_y m^4	Torsion Constant m^4	Dead load t/m	Live load t/m
Pylon	Hollow rectangular R.C. section (3x5m) with thickness of wall of 0.4 m.	300	5.76	17.88	7.4	15.9	14.4	0
Deck	Steel box girder in orthotropic plate shape	2100	1.25	1.14	30.5	31.69	5.78	5.28
Cables	6x37 classes IWRC [21] of zinc –coated rope with minimum ultimate of 925 tons	1584	.006194	Diameter =10.16 cm			0.004896	

Table(2): specifications for the lattice in Dover guyed tower.

Item	Units	Section (1)	Section (2)	Section (3)	Section (4	Section (5)	Section (6)
Cross- sectional area , A.	m^2	0.05023	0.03800	0.03429	0.02138	0.02138	0.007886
Polar moment of inertia ,I_z	m^4	0.0659	0.0498	0.0494	0.02800	0.02800	0.002194
Moment of inertia, I_x	m^4	0.03295	0.0249	0.0247	0.01400	0.01400	0.001097
Moment of inertia , I_y	m^4	0.03295	0.0249	0.0247	0.01400	0.01400	0.001097
Modulus of elasticity ,E.	t/cm^2	2059	2059	2059	2059	2059	2059
Weight / unit length	t/m	0.483	0.385	0.355	0.255	0.2515	0.088

Table(3) : specifications for the guys in Dover guyed tower.

Item	Units	Level No. 1	Level No. 2	Level No. 3	Level No. 4	Level No. 5
Diameter ,D.	m	0.03493	0.0381	0.04128	0.0508	0.03174
Cross- sectional area , A.	m^2	0.000802	0.000948	0.001109	0.001587	0.000633
Modulus of elasticity ,E.	t/cm^2	1600	1600	1600	1600	1600
Height of guys connections to mast.	m	44.5	95.7	146.91	198.12	228.6
Nominal radius of anchorage	m	71.93	71.93	149.96	149.96	172.21
Inclination on horizontal	Degree	31.74	53.08	44.41	52.88	53.00
Minimum ultimate load	Tons	112	132	155	232	90
Weight/unit length.	t/m	0.006169	0.007292	0.008531	0.01276	0.004871

Table (4) : data for calculations of drag forces in guys and lattice members.

Group member numbers	Solidity ratio	Area Effective m^2/m	Area of ancillaries m^2/m	Drag coefficient	
				Sub-critical regime	Super-critical Regime
Mast (1)	0.2159	0.459	0.34	1.830	1.590
Mast (2)	0.2000	0.423	0.34	1.900	1.670
Mast (3)	0.1953	0.410	0.34	1.928	1.691
Mast (4)	0.1732	0.360	0.22	2.045	1.812
Mast (5)	0.1786	0.371	0.21	2.045	1.830
mast (6)	-	1.524	-	-	0.700
Disk	-	4.000	-	-	0.700
All guys	-	Diameter , m	-	1.200	0.900

Table (5) : Effect of tension in cables on cable sag.

site	Coordinates		Sag values , m , T_u = 925 tons			
	x- axis	y- axis	10 % T_U	20 % T_U	30 % T_U	40 % T_U
1	10	10	0.582	0.194	0.146	0.116
2	20	20	1.059	0.353	0.265	0.212
3	30	30	1.429	0.476	0.357	0.268
4	40	40	1.694	0.565	0.423	0.339
5	50	50	1.853	0.681	0.463	0.371
6	60	60	1.906	0.653	0.476	0.381
7	70	70	1.853	0.681	0.463	0.371
8	80	80	1.429	0.476	0.357	0.268
9	90	90	1.429	0.476	0.357	0.268
10	100	100	1.059	0.353	0 265	0.212
11	110	110	0.582	0.194	0.146	0.116

Table (6): coefficient £ for cables in harp shape (new technique)

Connection type	Level of cables from upper part to lower part										
	1	2	3	4	5	6	7	8	9	10	11
A	0.29	0.260	0.234	0.200	0.184	0.171	0.165	0.160	0.158	0.158	0.159
B	0.278	0.250	0.224	0.200	0.184	0.171	0.163	0.159	0.157	0.157	0.157
C	0.310	0.270	0.230	0.200	0.180	0.165	0.155	0.149	0.145	0.138	0.125
D	0.283	0.254	0.227	0.205	0.187	0.174	0.163	0.152	0.137	0.112	0.069

Table (7) : coefficient £ for cables in radiating shape (new technique)

Connection type	Level of cables from upper part to lower part										
	1	2	3	4	5	6	7	8	9	10	11
A	0.296	0.252	0.212	0.178	0.154	0.138	0.128	0.121	0.115	0.103	0.082
B	0.258	0.231	0.205	0.181	0.162	0.148	0.139	0.134	0.113	0.122	0.107
C	0.306	0.261	0.220	0.185	0.157	0.138	0.124	0.112	0.101	0.086	0.068
D	0.290	0.251	0.216	0.185	0.160	0.141	0.127	0.115	0.103	0.087	0.068

Table (8) : coefficient £ for cables in fan shape (new technique)

Connection type	Level of cables from upper part to lower part										
	1	2	3	4	5	6	7	8	9	10	11
A	0.300	0.255	0.214	0.180	0.156	0.139	0.129	0.123	0.116	0.104	0.081
B	0.263	0.235	0.207	0.183	0.164	0.150	0.140	0.135	0.130	0.123	0.108
C	0.310	0.260	0.220	0.187	0.160	0.140	0.126	0.115	0.103	0.087	0.066
D	0.290	0.254	0.218	0.187	0.162	0.144	0.130	0.117	0.103	0.087	0.065

Table (9) : Maximum responses in cable-stayed bridges taking connection types into account.

Bridge type	Connect. Type,	Pylon Sway (m)	Pylon Moment m.t	Pylon Normal Tons.	Floor Beam deflection (m)	Floor Beam Moment m.t	Floor Beam Normal Tons.	Case of Initial tension
Harp Shape Cable Stayed Bridge	A	0.37	5942	-4400	-0.72	6154	-1370	10 % T_u
	A	0.11	1430	-4500	-0.16	2586	-1500	New tech.
	B	0.33	2547	-4317	-0.68	6146	-1381	10 % T_u
	B	0.13	1122	-4960	-0.19	3007	-1366	New tech.
	C	0.47	2251	-4378	-0.82	6144	-1320	10 % T_u
	C	0.13	458	-4400	-0.16	2471	-1350	New tech.
	D	0.35	5186	-4324	-0.68	6112	-1386	10 % T_u
	D	0.11	1683	-4312	-0.16	2821	-1271	New tech.
Radiating Shape Cable Stayed Bridge	A	0.35	6220	-4990	-0.69	6072	-1140	10 % T_u
	A	0.13	1516	-5006	-0.17	2085	-958	New tech.
	B	0.30	2212	-4928	0.65	5402	-940	10 % T_u
	B	0.12	762	-4990	-0.21	3191	-916	New tech.
	C	0.46	380	4142	-0.78	6308	-896	10 % T_u
	C	0.12	156	-4042	-0.15	2437	-924	New tech.
	D	0.39	2345	-4109	-0.71	6108	-900	10 % T_u
	D	0.10	678	-4036	-0.16	2652	-912	New tech.
Fan Shape Cable Stayed Bridge	A	0.35	3635	-4953	-0.69	6020	-1093	10 % T_u
	A	0.15	1588	-5016	-0.18	2670	-917	New tech.
	B	0.30	2323	-4935	-0.65	5887	-897	10 % T_u
	B	0.12	680	-4442	-0.22	3246	-873	New tech.
	C	0.45	2173	-4430	-0.77	6282	-841	10 % T_u
	C	0.12	560	-4335	-0.15	2468	-880	New tech.
	D	0.39	3800	-4554	-0.71	6045	-845	10 % T_u
	D	0.12	1133	-4190	-0.17	2677	-880	New tech.

Table (10): Statistic analysis for dynamic responses for guyed tower.

location	response	10 %T_u Maximum Value	10 %T_u Minimum Value	10 %T_u Mean Value	New technique Maximum Value	New technique Minimum Value	New technique Mean Value
Top tower	Lateral Sway (cm)	170	1	105	130	1	72
Level 1		129	0	78	101	0	51
Level 2		61	0	29	44	0	16
Top tower	Lateral Velocity m/sec.	-6.75	5.70	0.04	4.40	-4.15	0.02
Level 1		-3.45	-3.38	0.03	3.4	-3.11	0.01
Level 2		-2.31	1.97	0.01	-1.85	1.71	0.003
Cable No. 1	Tension(t)	34.76	8.75	22.88	38.06	17.51	27.56
Mast (1)	Normal forces in tower members(t)	-73	-8	-41	-83	-23	-52
Mast(2)		-226	-18	-128	-256	-38	-154
Mast(3)		-357	-17	-185	-412	-28	-216
Mast(4)		-541	-32	-299	-653	-27	-340
Mast (1)	Moment in tower members (t.m)	87	7	49	72	7	48
Mast(2)		345	-20	154	238	-3	129
Mast(3)		161	-101	32	105	-78	17
Mast(4)		191	-190	-24	-107	101	-7

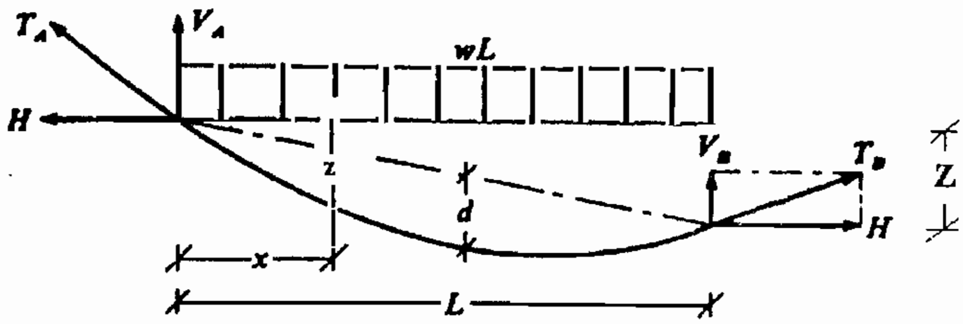


Fig (1):Simply supported cable with uniformly distributed load along the horizontal projection of the span

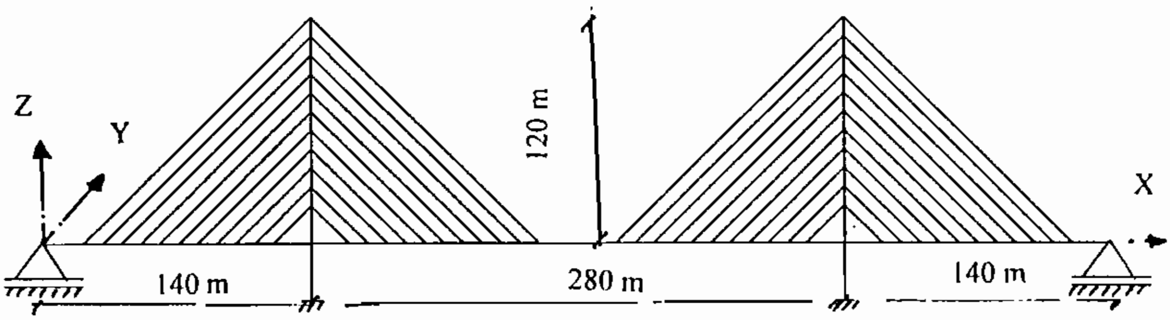


Fig.(2-a): Cable-stayed bridge in harp shape.

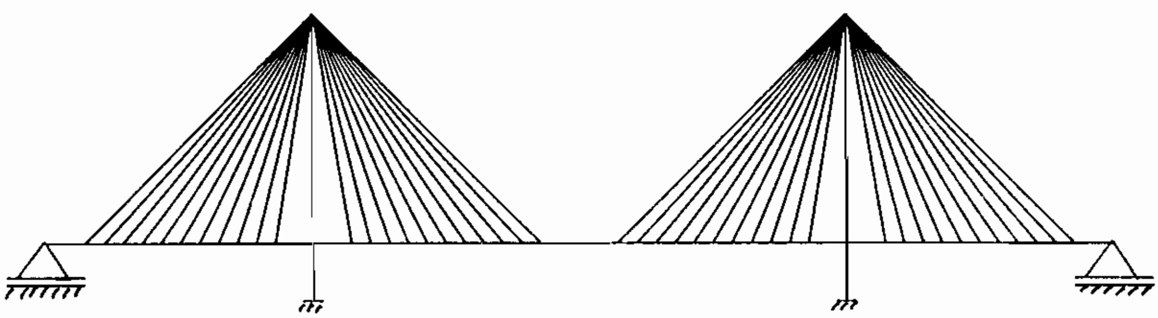


Fig.(2-b): Cable-stayed bridge in radiating shape.

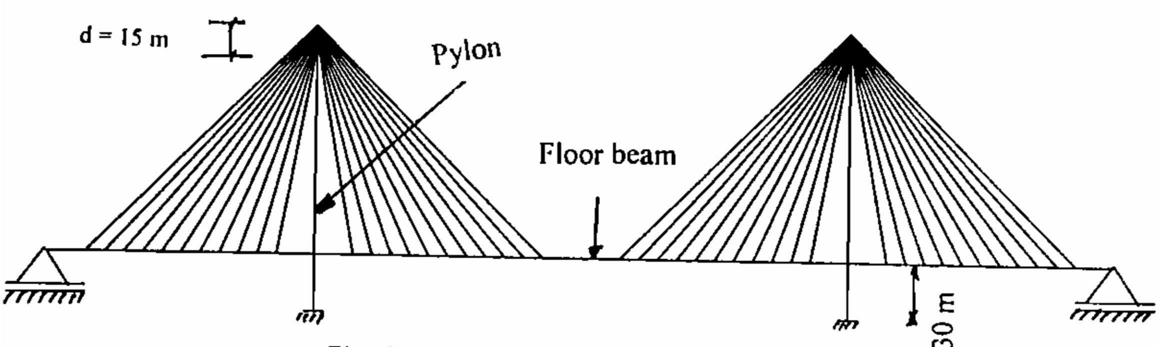


Fig.(2-c): Cable-stayed bridge in fan shape.

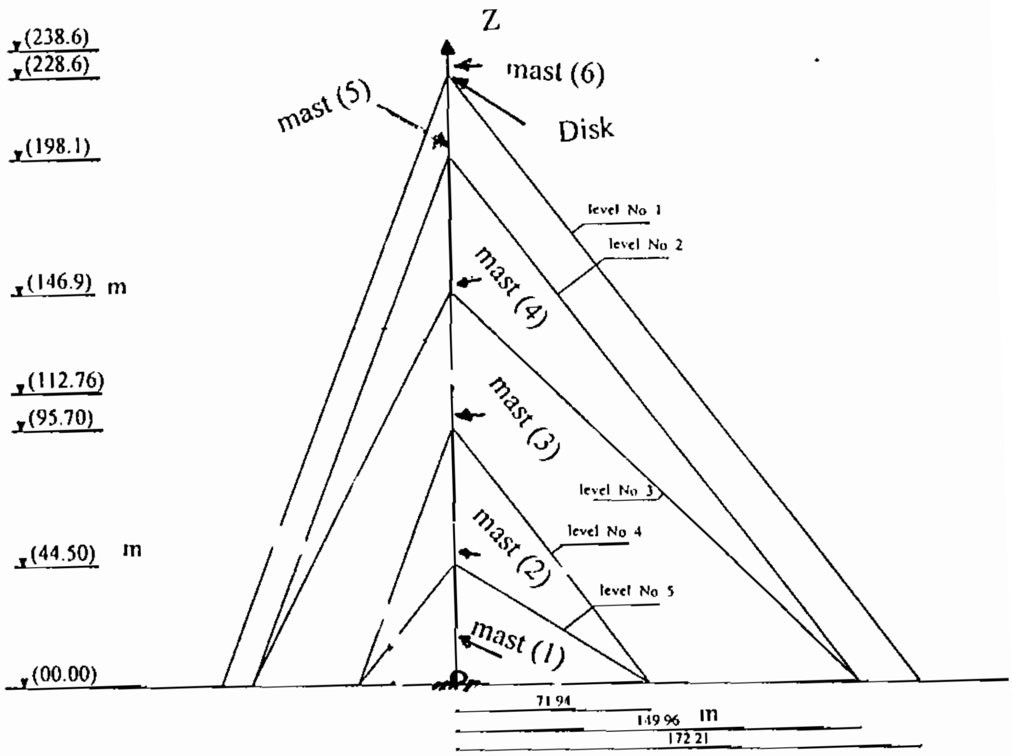


Fig.(2-d): Dover guyed tower.

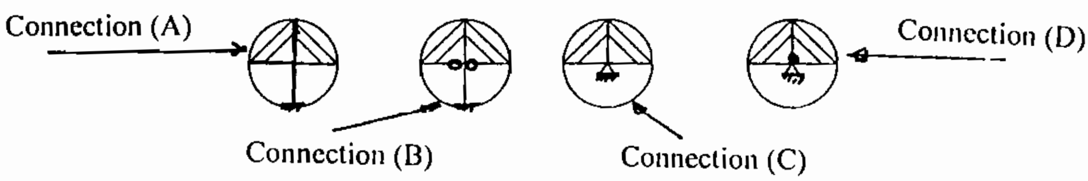


Fig.(3-a) : Connection types between pylons and floor beam.

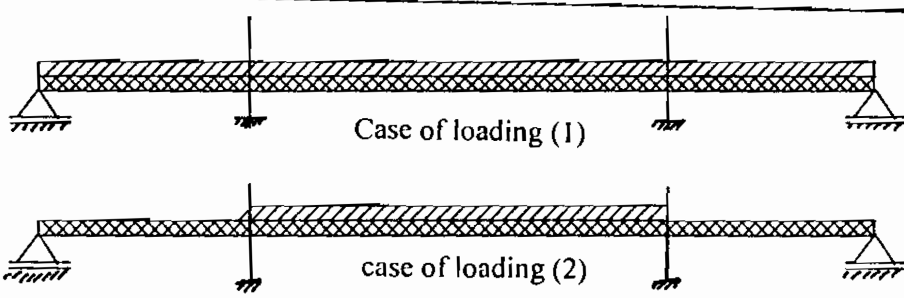


Fig.(3-b) : Cases of loading for cable–stayed bridges.

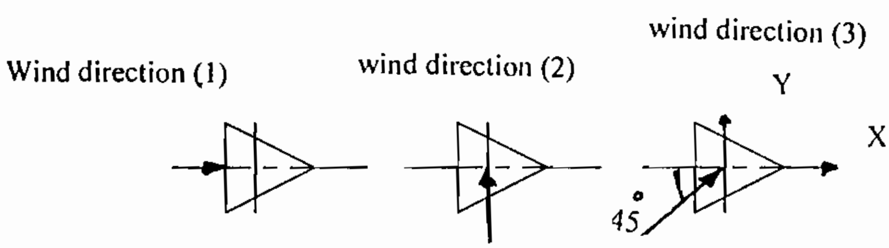


Fig.(3-c) : Case of loading for guyed tower.

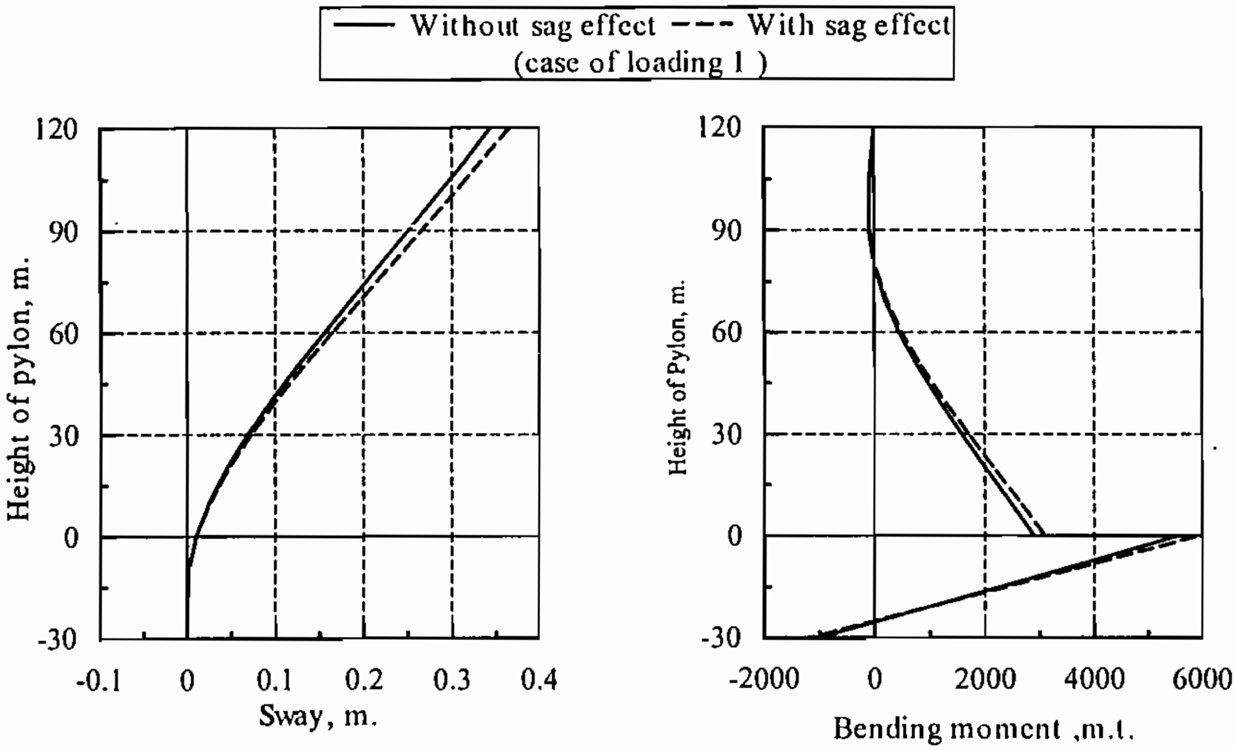


Fig.(4-a) : Variation of sway and moment along pylon height in harp shape(connection type A)

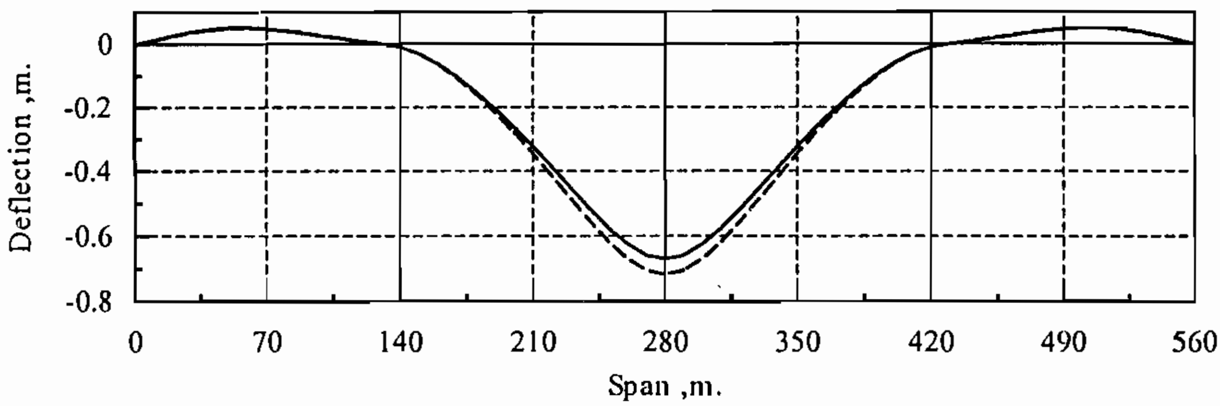


Fig.(4-b) : Variation of deflection along floor beam in harp shape(connection type A)

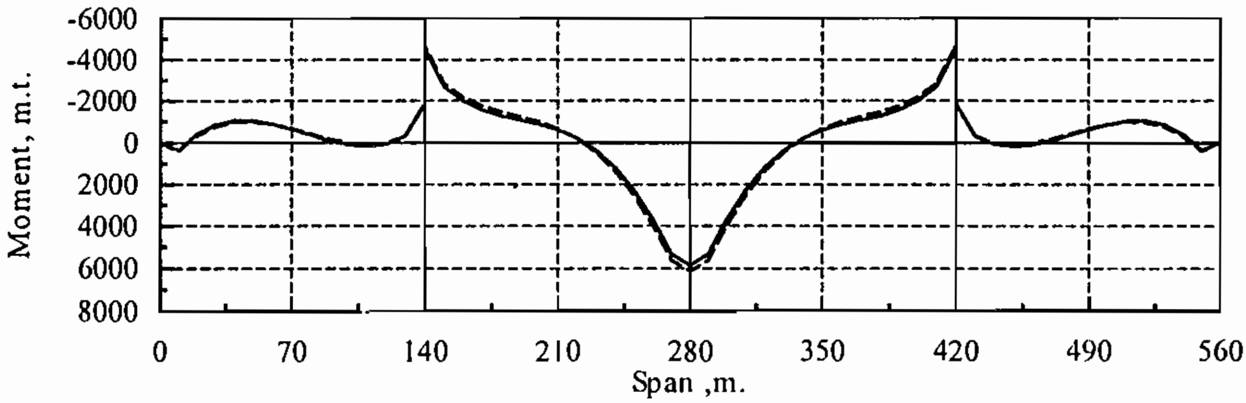


Fig.(4-c) : Variation of bending moment along floor beam in harp shape(connection type A)

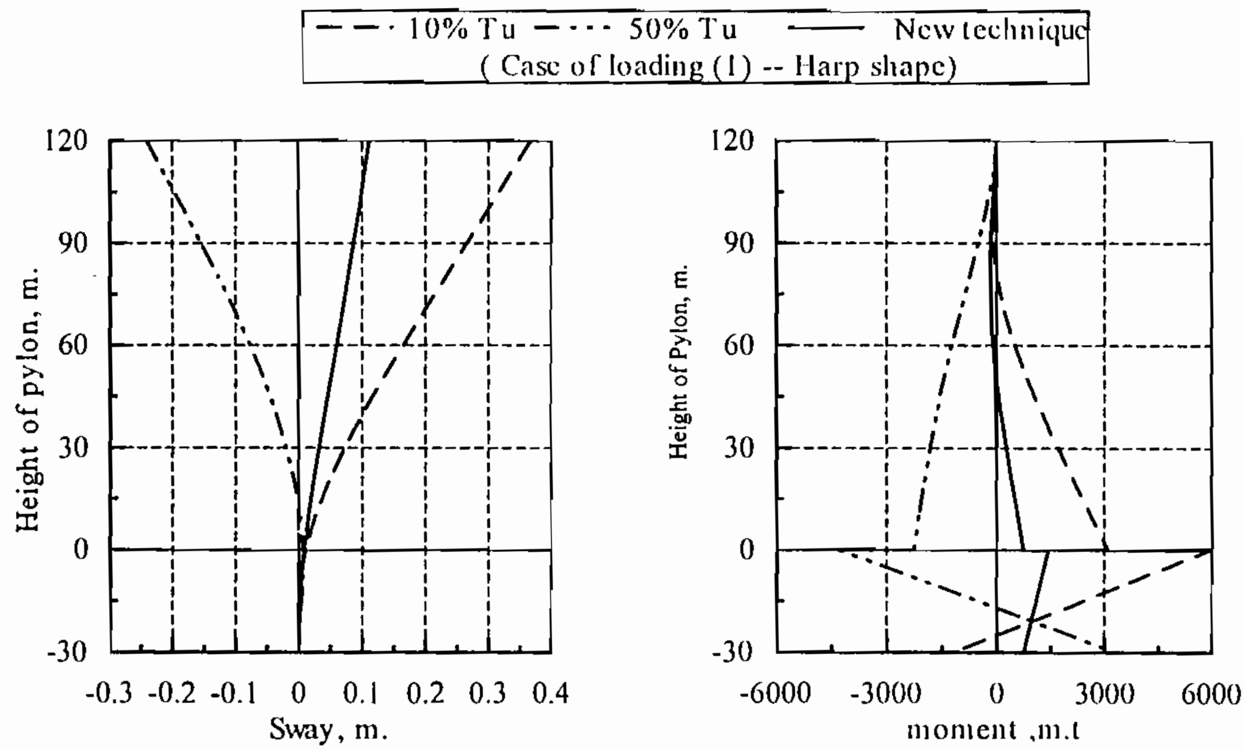


Fig.(5-a) : Variation of sway and moment along pylon (connection type A)

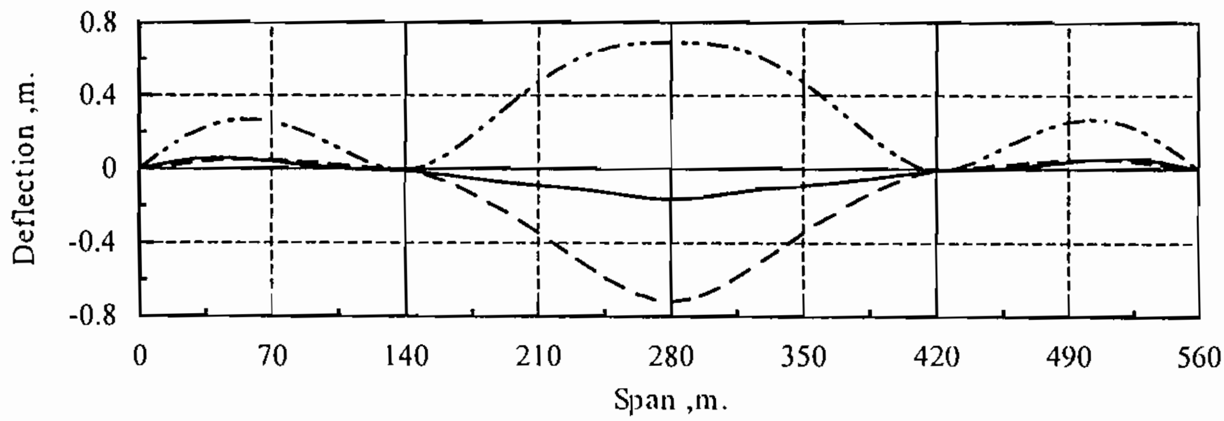


Fig.(5-b) : Variation of deflection along floor beam (connection type A)

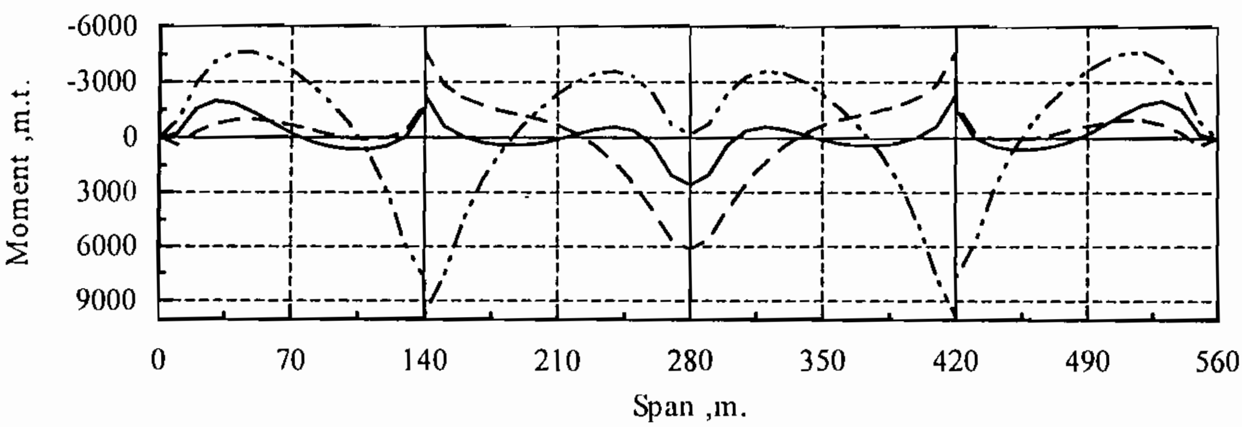


Fig.(5-c) : Variation of bending moment along floor beam (connection type A)

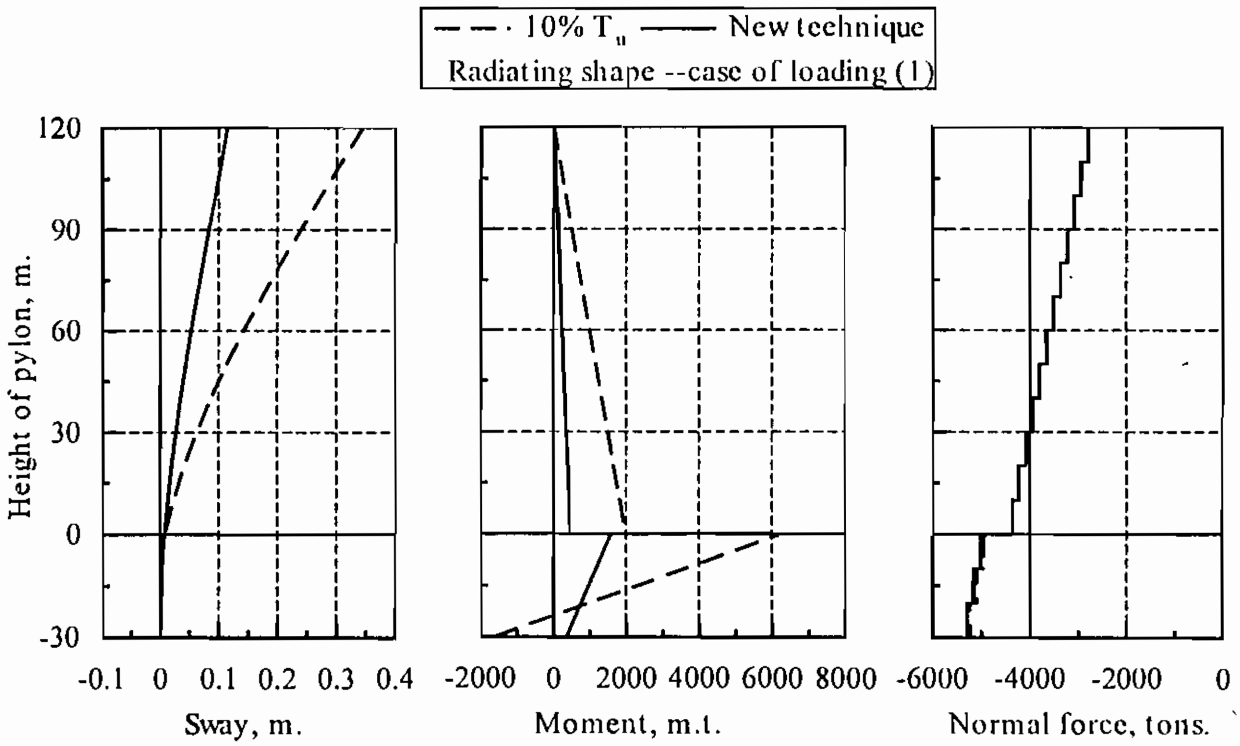


Fig.(6-a) : Variation of pylon responses (connection type A)

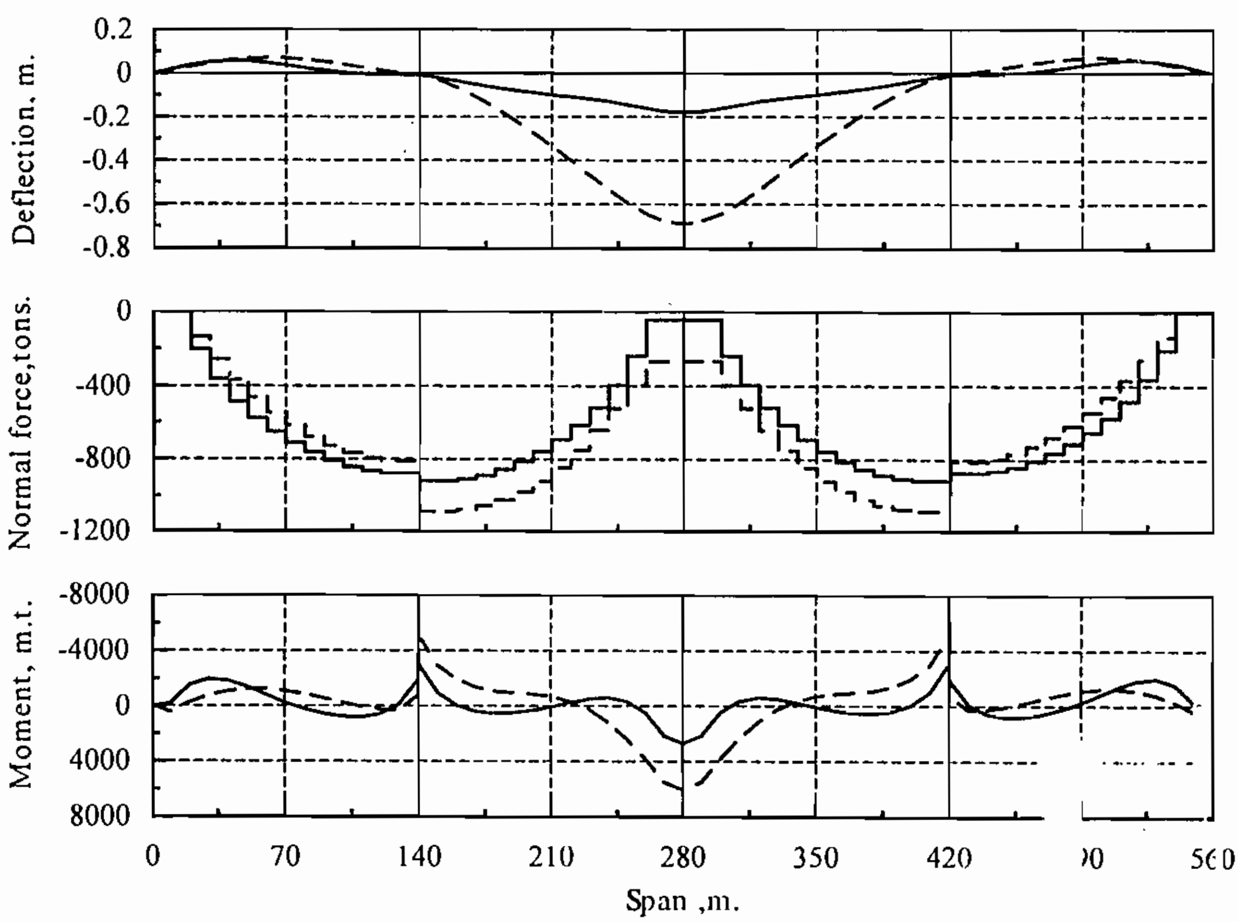


Fig.(6-b) : Variation of floor beam responses (connection type A)

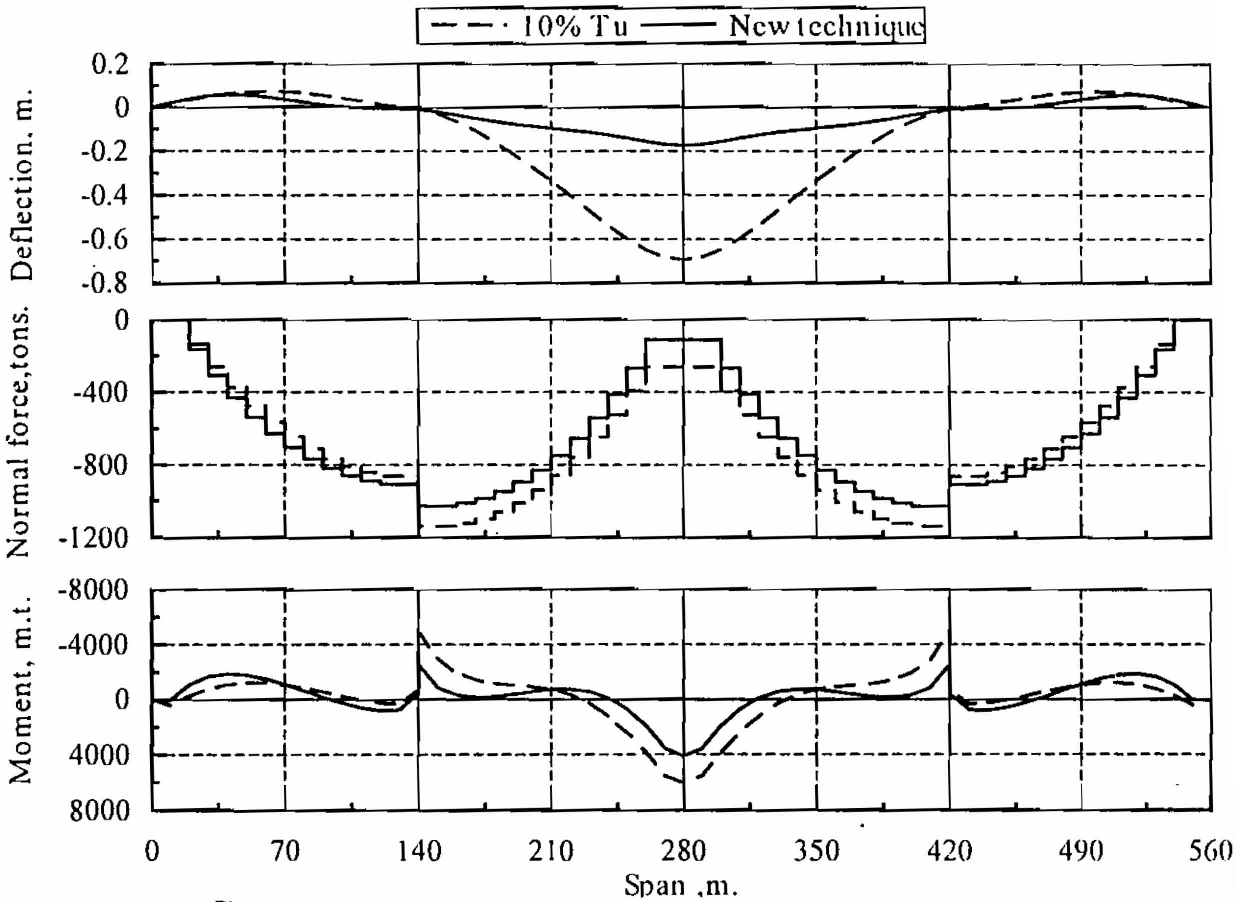


Fig.(7) : Variation of floor beam responses in fan shape, case of loading(1) and connection type (A).

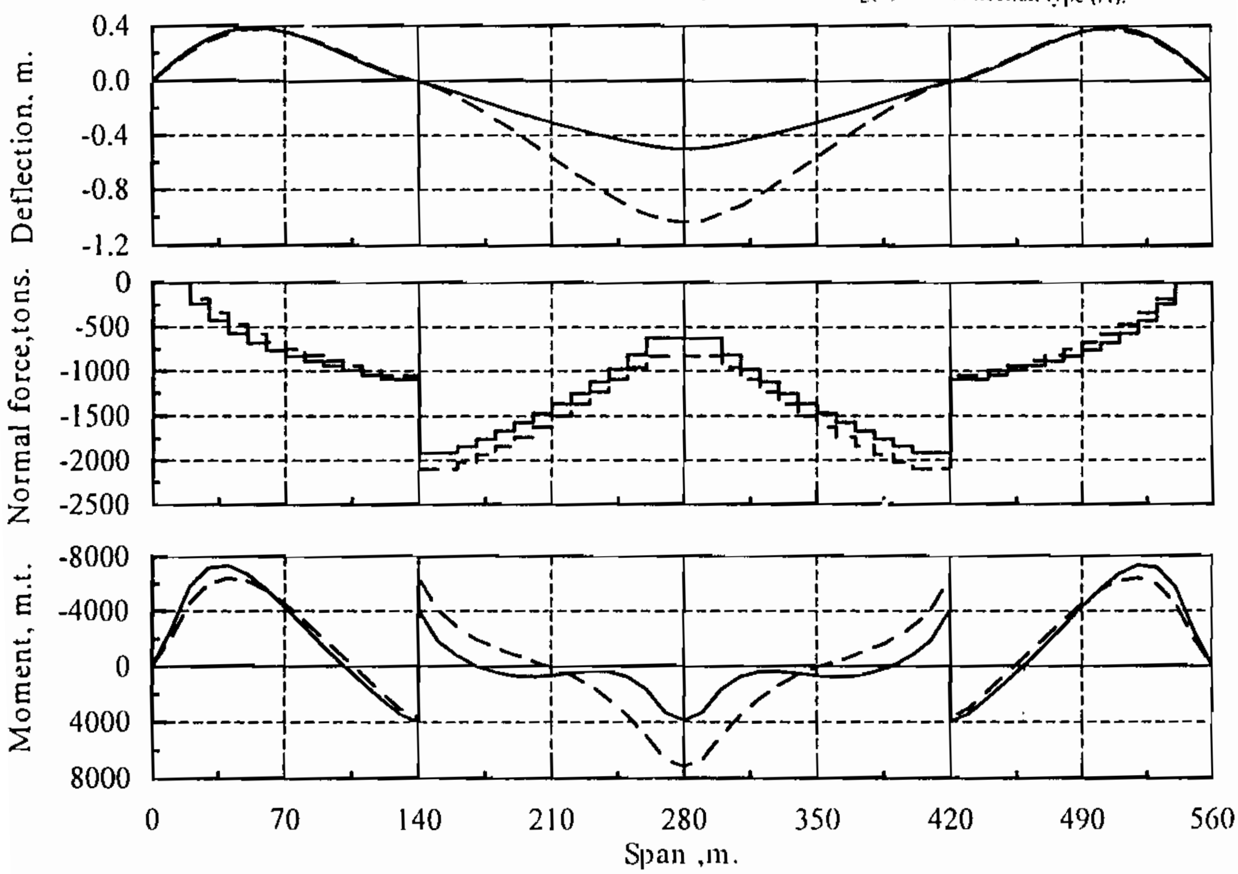


Fig.(8) : Variation of floor beam responses in harp shape, case of loading(2) and connection type (A).

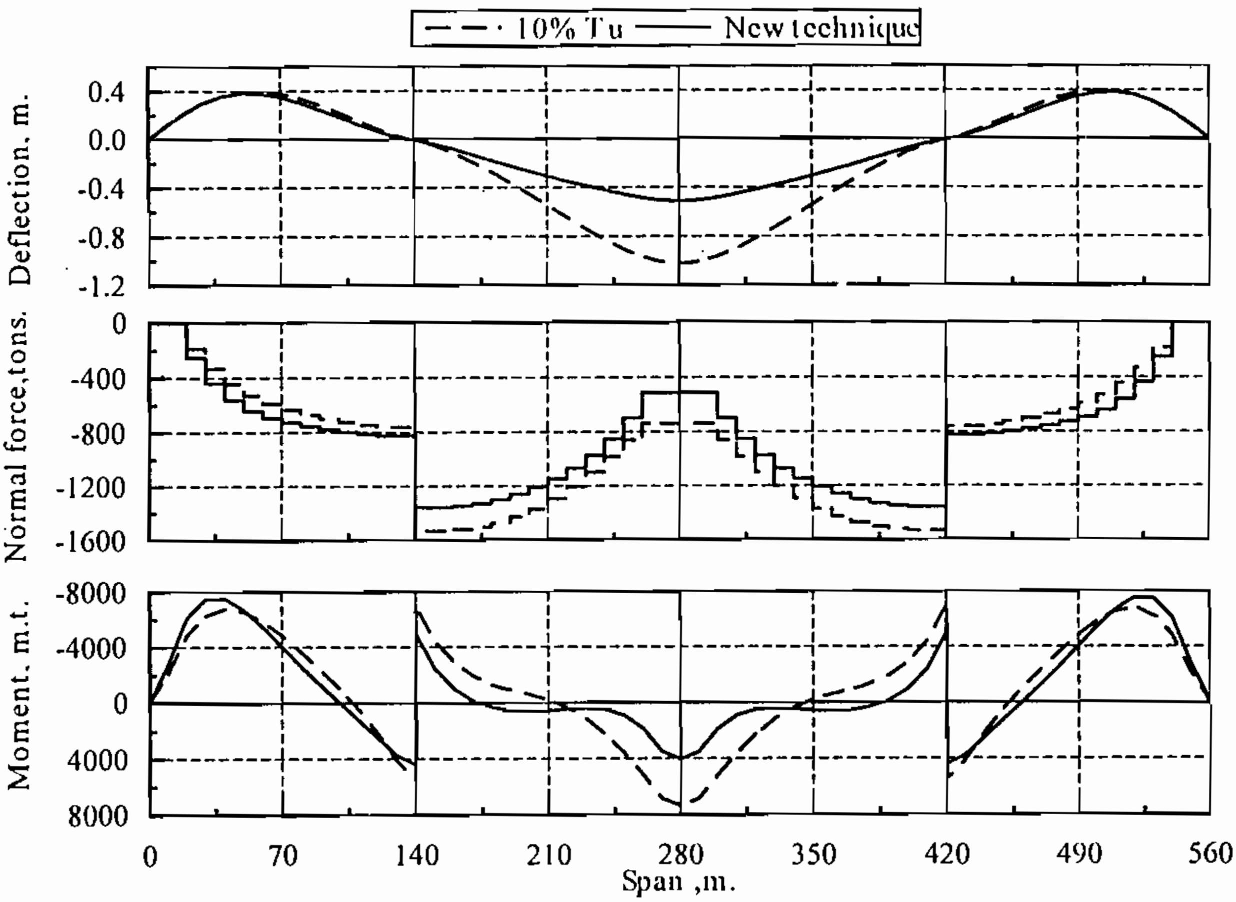


Fig.(9) : Variation of floor beam responses in radiating shape, case of loading(2) and connection type (A).

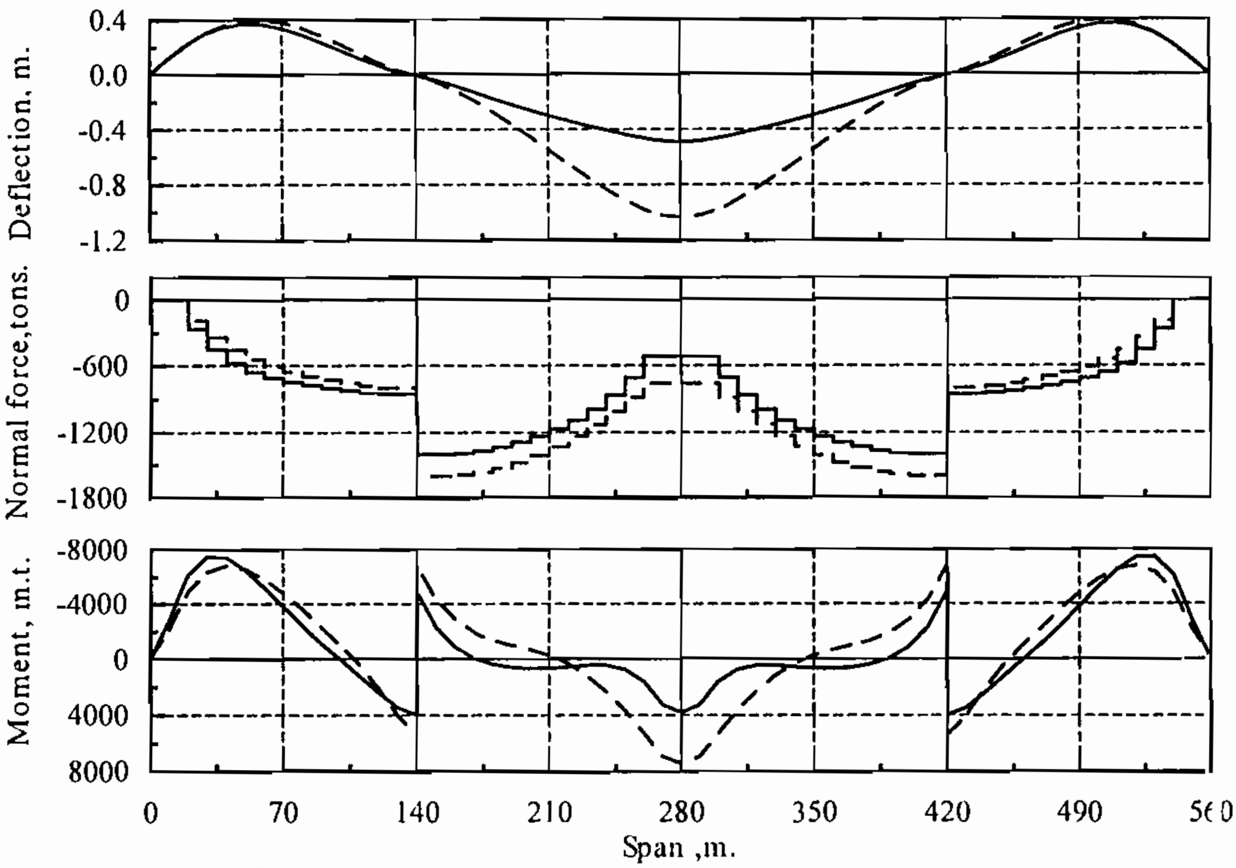
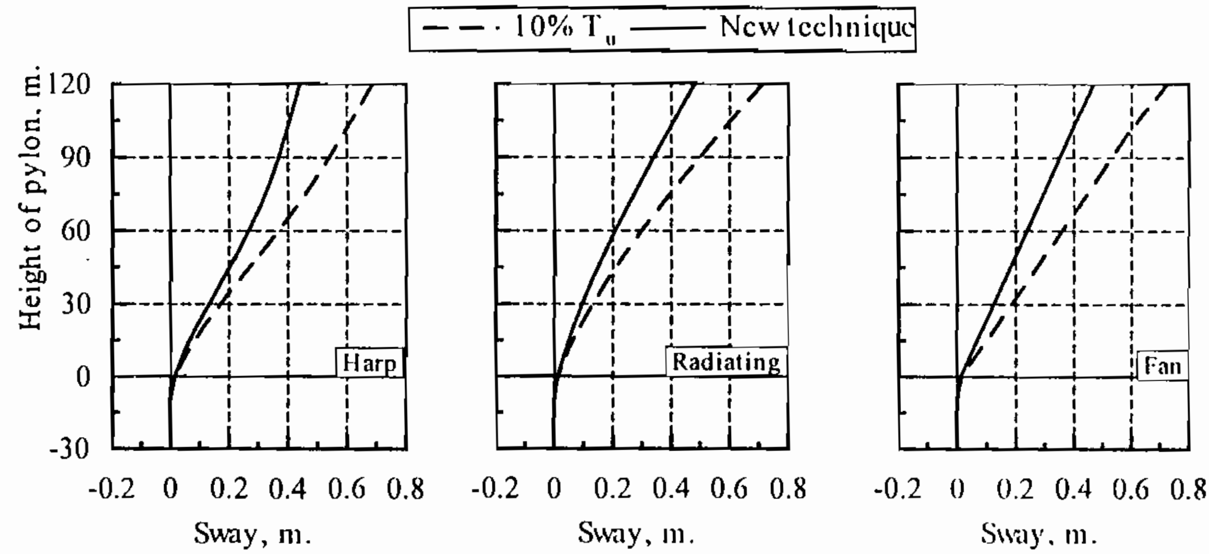
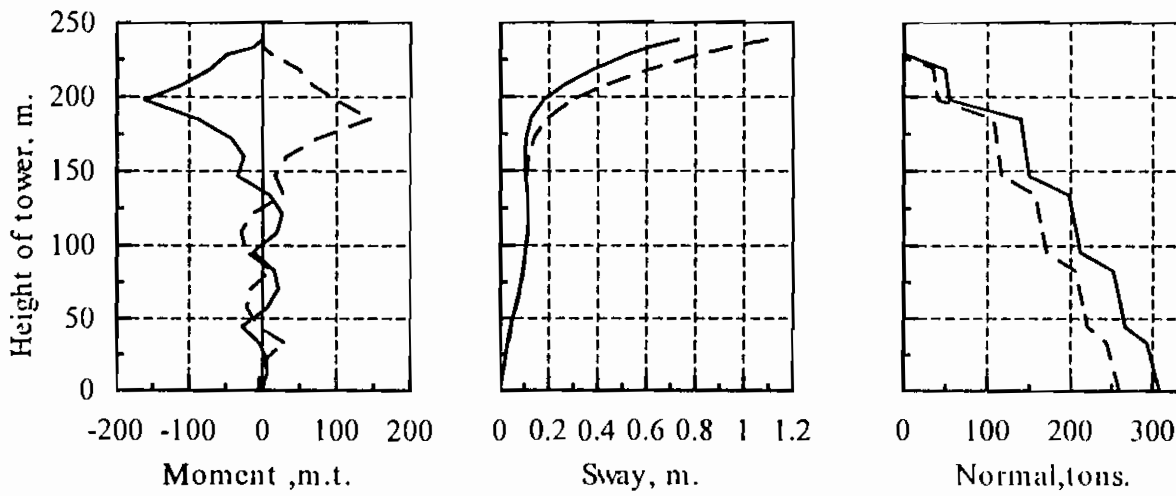


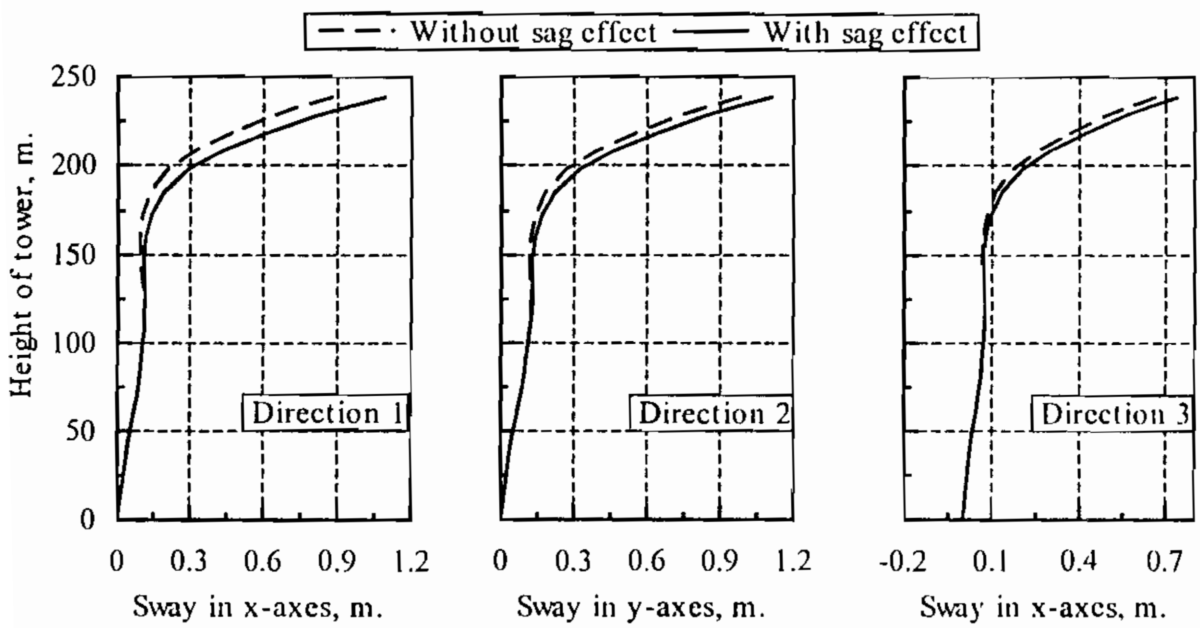
Fig.(10) : Variation of floor beam responses in fan shape, case of loading(2) and connection type (A).



Fig(11): Variation of sway along pylon height, case of loading (2).



Fig(12): Variation of various responses along tower height , wind direction (1).



Fig(13): Variation of sway along tower height.

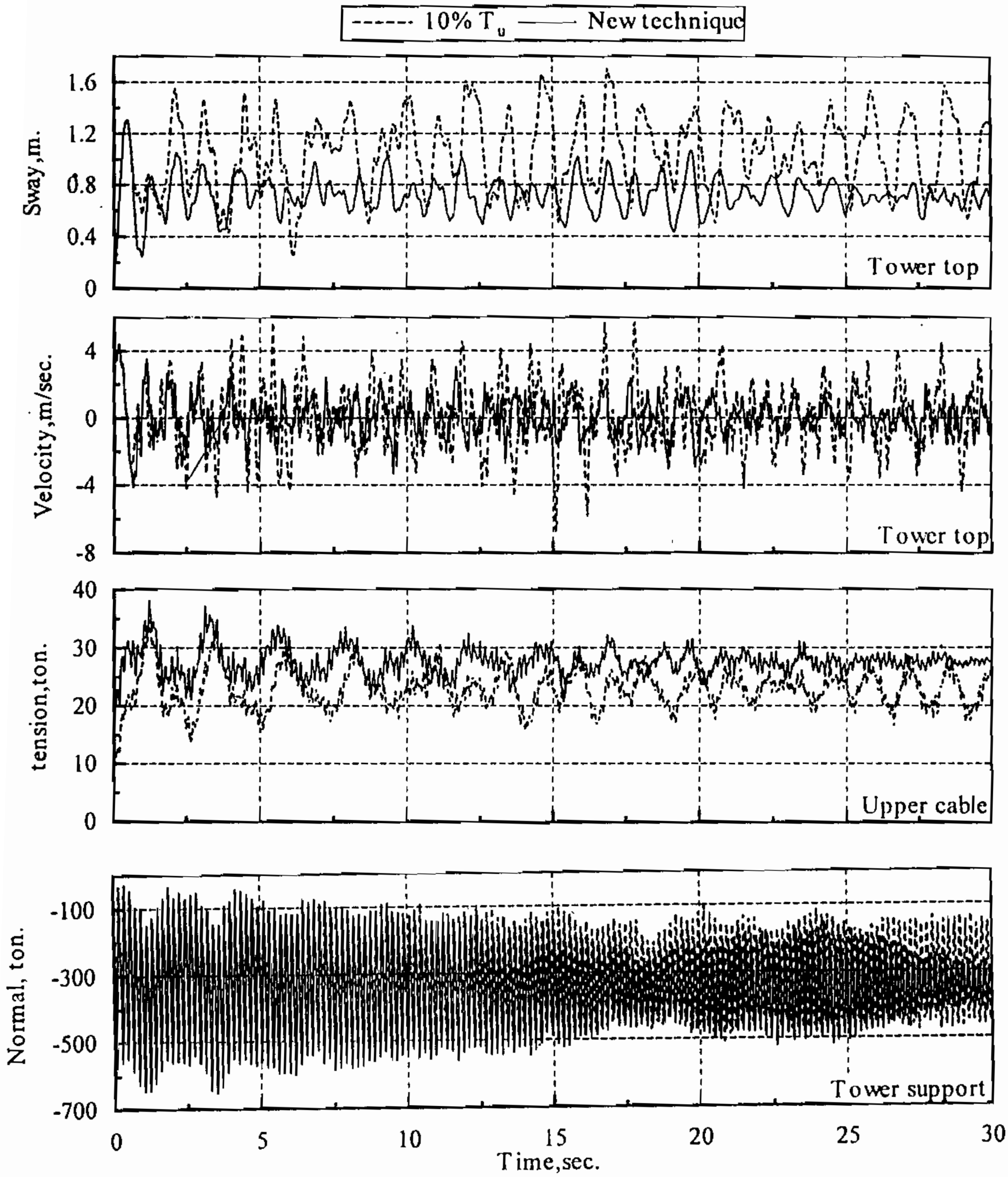


Fig.(13) : Variation of dynamic responses for guyed tower.