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Two Spans Cable Stayed Bridges.

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TWO SPANS CABLE STAYED BRIDGES

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الكباري ذات الاتساعين والارتكاز بالكابلات

الخلاصة:

إن الهدف الرئيسي لهذا البحث يتركزفي دراسة الكباري ذات الاتساعين صاحبة الارتكاز بالكابلات حيث تم دراسة ثلاثة أنواع منها شائعة الاستخدام وهى الكباري ذات الكابلات القيثارية والمروحية والإشعاعية الشكل آخذا في الاعتبار نوعين من التمثيل الرياضي أحداهما مفترضـــاالكابلات أحاديـــة المســـتوى والآخـــر ثنائيـــة المستوى ولمعرفة أفضل الأنواع من هذة الكباري تم عمل المقارنات المختلفـــة وذلـــك بعـــد إجـــراء التحليـــل الاستاتيكى لحالات تحميل مختلفة متماثلة وغير متماثلة وذلك للأحمال الخاصة بحركة العربات والمارة وأحمال الرياح في الاتجاهين الطولي والعرضي لاتجاهات هذة الكباري وقد تم دراسة تأثير الأنواع الشائعة الاســـتخدام من الوصلات بين البرج وسطح الكوبري وكذلك نسب ارتفاع البرج إلى اتساع الكوبري وكذلك ترتيب الكابلات في اتصالها مع البرج للكباري مروحية الشكل وقد تم تدوين تأثير كل هذة العوامل على قيم الشد النهائي فـــي الكابلات وكذلك القوى المحورية وقوى العزوم المختلفة وقيم الترخيم والازاحات المختلفة في العناصر الإنشائية المكونة لهذة الكباري وبعد الوصول إلى الحالات المثلي تم دراسة الترددات الطبيعية الأساسية لنـــوعين مـــن الأنواع الثلاثة موضوع الدراسة ثم تم إجراء التحليل الديناميكي لهم وذلك لمعرفة سلوك هذة المنشاءات خلال الزمن وقد تم استخدام برامج الحاسوب المعدة لهذا الغرض بمعرفة الباحث والمبنية على استخدام طريقـــة الطاقة المبنية علي تصغير طاقة الوضع باستخدام طريقة الانحدارات المتبادلة والتي أثبتت كفاءة عالية آخـــذا في الاعتبار لا خطية سلوك المشاءات وفى النهاية تم تدوين أهم النتائج.

Abstract

This paper is concerned about the study of two spans cable stayed bridges. Three common types of these bridges as harp, radiating and fan shapes are considered. The static analysis considering single plane and double planes of cables as the mathematical models is carried out. The variations of pylon height to span of the bridge in all cases, the influence of connections between pylons and deck floor and the arrangements of cables are the major factors of this work. The effect of symmetrical and asymmetrical loads such as, the own weight of all structural elements, traffic load including impact, and wind loads in longitudinal and transverse directions of the bridges are taken into account. The study of fundamental natural frequencies is investigated. Finally, the dynamic analysis in time domain for some special cases is presented. In both static and dynamic analysis, 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 the iterative steps to acquire the final configurations. The author constructed all computer programs used in the analysis. The major conclusions, which have been drawn from the present work, are outlined.

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1- Introduction

A cable stayed bridges consists of three principal components, namely girders, pylons, and inclined cable stays. The girder is supported elastically at points along its length by inclined cable stays so that . can span a much longer distance without intermediate piers. The most common cable stayed bridges may be classified to harp, radiating and fan depending on the arrangements of cables and their connections with pylons. The dead and traffic loads including impact on the girders are transmitted to the pylons by inclined cable stays. To get the best configurations of cables and the optimum pylon height, many parametric studied are taken into considerations. The major of these parameters are the arrangements of cables, height of pylon to span ratios (H/L), the height of fixing cables with pylon to the height of pylon (d/H) in bridges having fan shape, and effects of the symmetrical and asymmetrical loading on the final responses. Starting with H/L equals 0.20 (in which H is the pylon height and L is the bridge's span) and ending of 0.60 with interval of 0.1, the static analysis is carried out taking into account the symmetrical gravity load only. Then, we fixed H/L with 0.425 (H= 102 m, and L= 240m) for other study parameters (asymmetrical gravity loads, wind in longitudinal and transverse directions). Because of the complete dynamic analysis must includes the frequency analysis, the fundamental natural frequencies and their corresponding normal modes are computed The program used for computation the natural frequencies and their corresponding mode shapes was SAP 2000. The dynamic analysis with total time of 1 minute and time step as 0.02 second (3000 time steps) and damping as 0.02 for some special cases is carried out. In the static and dynamic analysis, 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 a computer program based on the iterative scheme taking geometric nonlinearity into account. The Euclidean norm of the gradient vector or unbalanced force vector is taken as 0.01% and 0.1% of its initial value for static and dynamic analysis, respectively. Main sources of knowledge about this method are given in [1], [2], [3], [4], [5], [6], [7], and [8]. Finally, the results of such analysis are used to investigate the factors that affect the response of cable stayed bridges. The all obtained numerical results for all cases are discussed and compared. Finally, the major conclusions are presented.

2. Mathematical model.

Both mathematical models as single plane and double planes of cables are considered [9]. The first mathematical model considering single plane of cables with global system of coordinates for bridges having harp, radiating, and fan shapes is shown in Fig.(1-a), (1-b), and (1-c), respectively. The second mathematical model considering double planes of cables is shown in Figs. (3-a), (3-b), and (3-c) for harp, radiating, and fan bridges, respectively. All bridges have two spans of 240 m, each and fifteen cables in each side of pylon. The cables were 6x37 classes IWRC (independent wire rope core) of zinc-coated bridge rope [10]. The cables have an area of 48.7741 cm2, diameter of 10.16 cm, own weight of 39.34 kg/m, modulus of elasticity of 1584 t/cm2 and maximum breaking loads of 730 tons. The pylon is designed as reinforced concrete with hollow rectangular uniform section having 3 m, width (parallel to X-axis) and 5 m depth (parallel to Y-axis) with thickness of walls as 0.40 m. The pylon own weight is 14.4 t/m. The decks were taken as steel box-girder in orthotropic plate shape with longitudinal rips. The own weight including asphalt as 4.17 t/m for each main girder. The cross girders consist of built-up I-section with web plate 200x1.4 cm and two flange plate of 40x1.2 cm in each side. The strut between pylons has a square reinforced concrete section with 1m. The cross section of the orthotropic deck floor and its properties is shown in Fig.(4). Also, the cross sections of pylon, strut, and X-girders and their properties are shown in Fig.(5).The width of the bridge is 21m. In case of connection type a ,the first and second mathematical models have 950 and 1900 degrees of freedom, respectively.

3. Wind assumptions.

It is convenient to express the velocity as the sum of the mean velocity U(z ,x) in the long-wind direction at height z and the fluctuating time-dependent components u(z ,x ,t), u(z, y ,t), and u(z ,z ,t) where x represents the along-wind , y the horizontal across wind and z the vertical across-wind directions at height z. Because of the horizontal and vertical crosswind fluctuations are of secondary importance, the instantaneous wind velocity can be treated as a scalar quantity, in which case, omitting the direction indicator, the instantaneous velocity at height z is given by:

$$V(z,t)=U(z)+u(z,t) \qquad (1)$$

As a result , the response of the structures to wind can be divided into two parts:

1.The quasi-static response caused by the mean wind velocity component, and

2.The response due to fluctuation wind velocity that is the source of dynamic excitation.

The most generally law describing the way in which the mean velocity varies with height, Z, is the "logarithmic law" and is given by:

$$U(z) = 2.5\, u^* \ln (Z/Z_o) \qquad (2)$$

All solved examples in this research considering wind , the following assumptions are taken into consideration. The deck floor has a level of 10m above the ground with mean wind speed as 60 km/hour. The shear velocity of wind and the roughness length are taken as 1.703 and 0.2, respectively. The area exposed to wind for cables is taken as 0.1016 m2/m and the drag coefficients varies between 0.9 and 1.2 according to flow air regime. The area exposed to wind for pylon in longitudinal and transverse wind directions are taken as 5 and 3 m2/m, respectively .Also the area exposed to wind for decks in longitudinal and transverse wind directions are respectively taken as zero and 4 m2/m. The drag coefficients for both pylon and floor beam is considered as 2.

4. Connection between pylon and floor beams.

In order to take into account the influence of connections types between pylon and floor beams, four cases are considered [11], as shown in Fig. (2).They are given as:

a)The connection between pylon and deck is rigid, while the pylon base is fixed and other two supports are rollers, Fig. (2), Case (a).

b)The intersection between floor beam and pylon is pinned for floor beam, while the pylon base is fixed and other two supports are rollers, Fig. (2), Case (b).

c)The lower parts of tower is released and the deck girder is continuous with rigid attachments with pylon on roller supports except hinged for middle support, Fig.(2), Case (c).

d) This case likes case c instead rigid connection of pylon to pin, Case (d).

5. Cases of loading.

Four cases of loading are taken into consideration. With symbols mentioned later , these cases are:

1.Load (1) = D.L+L.L.
2. Load (2) = D.L+L.L + W.L
3. Load (3) = D.L+L.L + W.T.
4. Load (4) = D.L+L.L on left span and D.L only on right span.

6. Cases study

First, in addition to the previous assumptions, the static analysis for all considered cases is carried out with a uniformly distributed live loads along all spans lengths with intensity of 5.06 t/m'. The initial tensions of cables in all cases are taken as 73 tons (10 % of maximum breaking loads). The various static responses for various cases are shown in Figs.(6to14). The variations of maximum various static responses considering wind in longitudinal and transverse directions are given in Table (1).The first four frequencies for both harp and radiating shapes with single plane and double planes of cables are given in Table (2). Also, the first and second mode shapes for bridges in harp and radiating shapes are shown in Fig.(15) and Fig.(16), respectively. Considering case of load (2), some variations with time of the dynamic displacements at mid upper cable in X-axis ,and the dynamic deflection at mid floor beams in harp shape are shown in Figs.(17) and (18), respectively. The corresponding velocity and acceleration histories are shown in Figs.(19 to 22). The maximum dynamic stress in floor beam is given in Fig.(23) , and the dynamic bending moment in floor beam at 228m from left support for harp shape is shown in Fig.(24). Finally, some statistic analysis for some dynamic responses in pylons, floor beams, and cables are given in Tables 4 ,5 ,and 6, respectively.

7. Analysis of Results

a) Effect of pylon height to span ratio (H/L) (Table 3 and Figs. 5 to 9):

With reference to the symbols given in item 8 and Table(3) ,it can be concluded that:

1.An increasing of (H/L) ratio leads to decreasing in all responses(final tensions in cables, longitudinal and lateral sways along pylon height, and deflections, normal forces, and bending moments along floor beam) in harp, radiating, and fan bridges. So that. this ratio confirms that it is the significant parameter on the all bridge responses , except the final tensions in cables.

2. The variations of final tension in cables have a less influence , especially in radiating and harp shapes.

3. The variations in responses for bridges having radiating and fan cable shapes are very close to others, but harp shape has the biggest responses and big difference in variations.

b) Effect of (d/H) ratio in bridges having fan shape (Fig. 10):

It can be concluded that:

1.An increasing of (d/H) ratios from 0.05 to 0.50 leads to accompaniment of decreasing from:

0.2 to 0.19 in €,

L/350 to L/410 in Δ,

1.35 TO 0.81 in ∂.

1.4 % to 1.3 % in μ.

2.The best choice for d/H ranges between 0.05 to 0.10.

c) Effect of asymmetric loads and connection types (Figs. 11 to 14):

It can be concluded that:

1.Case of asymmetrical loads (load 4) causes a great effect on the deflections and the bending moments along floor beam which these values became between twice or three times of their corresponding values in case of symmetrical loads. The values of normal forces along floor beam are decreased in compared by symmetrical loads..

2. The connection types between pylons and floor beams play a reasonable influence on the final responses. They have an influence on final values of tension in cables, normal forces and bending moments in towers and decks and the lateral sways in towers and vertical deflections in decks. In all phases , we can say connection types b and c are better than connection types a and d in all types of bridges shapes.

d) Effect of wind loads (Table2):

1.The final tension in cables ,normal forces in pylons and normal forces in floor beams have a small effect considering wind direction.

2. Case of transverse wind induces a big transverse sway in pylons , a small transverse motion in floor beam, and bending moments out of plane in the floor beam.
3.The mathematical model as double plane of cables is valid to analyze the bridges with all cases of loading, especially case of wind in transverse direction.

e) Natural frequencies analysis (Table 2 and Figs. 15 and 16),[12,and 13] :
A frequency analysis for cable stayed bridges is an essential step to complete their dynamic analysis.
f) Dynamic analysis in time domain (Tables 4 to 6 and Figs. 17 to 24):
For time domain analysis with 1minute as total time , time step as 0.02 sec., and damping as 0.02.,it can be concluded that:
1.The mean values for all responses in time histories and the corresponding static responses are very coincidences to others with difference does not exceed than 5 %.
2. All the dynamic responses(displacements, velocities, and accelerations) vibrate about its mean values with decreasing amplitudes towards the static values.
3. Considering the mean values of the most dynamic responses, radiating shape of cables has the superiority.
4. The maximum responses in dynamic analysis is bigger than these obtained from static analysis. These values in dynamic time histories = Ω times corresponding values in static analysis , where Ω is equal to:
1.50 – 1.90 (normal forces in pylons);
1.80 – 5.00 (sway in pylons);
10.0 – 200 (bending moments in pylons);
1.55– 1.80 (deflection in beams);
1.55 – 1.80 (bending moments in floor beams);
1.85 – 2.50(normal forces in beams);
1.50- 1.90 (shear force in beams);
1.90 – 3.90(horizontal displacements in cables); and
1,50 - 1.60 (final tensions in cables).
5. The mean values for all velocities and accelerations histories are very near to zeros.
6.The first mathematical model in most cases is dynamically sensitive more than the second one with small difference.
7. The statistic analysis (mean and maximum values) for dynamic stresses in both pylon and floor beams in single and double planes of cables are very close to others.
8. The maximum dynamic stress in harp shape equals 2 times in radiating shape. The both values in single and double planes of cables are very close to others. In harp shape the maximum dynamic stresses in pylon and floor beams are 311 and 1850 kg/cm2 ,respectively. They are 307 and 913 kg.cm2 in radiating pylon and floor beam , respectively.

9. conclusions:

The investigations built on the factors that affect the behavior of the two spans cable stayed bridges in this research , have led to the following conclusions:
1.The pylon height to span ratios (H/L) are assuredly the most important parameter affected the behavior cable stayed bridges.
2.The connection types between pylon and floor beam represents a big factor in the analysis. In all phases , we can say connection types b and c are better than connection types a and d in all types of bridges shapes.
3.The effect of (d/H) ratio in fan shape bridges has a small variations on responses .
The best value ranges between 0.05 to 0.1
4.Case of asymmetrical loads (load 4) causes a great effect on the most responses.
5.The wind in the transverse direction on the bridges induces a big transverse sway on pylons .
6.The mathematical model considering double plane of cables is the best choice

and valid for all symmetrical and asymmetrical cases of loading.

7.A frequency analysis for cable stayed bridges is an essential step to complete their dynamic analysis

8.The time domain dynamic analysis is very important which gives a complete dependence in the analysis of cable stayed bridges.

9. Radiating shape bridge is better than fan shape and both are better than harp shape.

10-Symbols:

The following symbols are used in this paper:

D.L.=own weight of structural elements including weight of asphalt (dead load).

L.L.= an equivalent uniform traffic loads including impact as live loads.

W.L= wind loads in the longitudinal direction of the bridge.

W.T= wind loads in the transverse direction of the bridge.

u* = the shear velocity or friction wind velocity, and

Zo = roughness length.

T = maximum final tension in cables,

T-ultimate = the minimum ultimate strength in cables (730 tons),

ϵ = the ratio of T/ T-ultimate,

H = the height of pylon above floor level,

L = the span of the bridge (240m),

H/L =pylon height to span ratio,

d = the height of pylon part to fix cables in fan shape,

d/H = the fixing cables to pylon ratio,

w = the total gravity loads(D.L+L.L)= 9.23 t/m',

Δ = the maximum deflection in the floor beam,

S = maximum sway at top of pylon ,

∂ = the factor multiplied of awl to represent the normal force in floor beam (tons), and

μ = the factor multiplied by wL2 to represent the bending moment in floor beam(tm).

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Table (1): Variations of various responses considering longitudinal and transverse wind.

Bridge Type	Response	Wind in longitudinal direction (case 2)				Wind in transverse direction (case 3)			
		Type a	Type b	Type c	Type d	Type a	Type b	Type c	Type d
Harp	Sway at pylon	4.57	3.57	2.03	1.37	63.46	63.6	99.41	18.02
Radiating	top	4.92	4.57	2.36	1.56	56.65	56.7	64.67	18.97
Fan	in direction of wind (cm)	4.7	4.2	2.2	1.54	57.2	57.3	65.5	19.2
Harp	Maximum	89.38	88.1	87.1	85.7	12.5	12.51	0.93	0.66
Radiating	deflection in	60.22	59.33	58.26	57.46	12.36	12.36	0.85	0.70
Fan	floor beam (cm)	62.6	61.77	60.77	58.1	4.61	3.86	0.58	0.60
Harp	Maximum	5963	5963	4520	4520	5963	5963	4521	4519
Radiating	normal force in	6012	6011	4780	4780	6012	6012	1784	1781
Fan	pylon (tons)	6000	6000	4615	4615	6004	6006	4624	4623
Harp	Maximum	1511	1360	298	515	2839	2842	74	1303
Radiating	bending	1553	1738	340	667	2898	2900	274	1343
Fan	moment in pylon (tm)	1508	1655	381	179	1432	1290	118	68
Harp	Maximum	2992	3003	2994	2987	2980	2980	2984	2982
Radiating	normal force in	1807	1809	1809	1807	1809	1796	1799	1799
Fan	floor beam(tons)	1903	1900	1906	1908	1914	1918	1918	1917
Harp	Max. moment in	10727	7250	10665	10645	10646	7987	10616	10644
Radiating	plane in floor	6836	6774	6731	6672	6774	6592	6527	6535
Fan	beam(tm	6933	6875	6840	6785	6711	6752	6652	6654
Harp	Max. moment	0	0	0	0	2206	2211	1601	1132
Radiating	out of plane in	0	0	0	0	2150	2034	1493	1216
Fan	floor beam (tm)	0	0	0	0	1092	860	1025	994
Harp	Final tension in	198.9	198.4	199.5	199	196.6	196.6	197.7	197.5
Radiating	cable (5), tons	171.5	170.5	171.7	169.1	168.3	168.3	169.1	169
Fan		173.8	172.8	174.2	173.4	170.7	171	171.7	171.7
Harp	Final tension in	229.2	229.4	229.7	229.6	230.5	230.5	231	231
Radiating	cable (10), tons	189.5	190.1	190.3	191.8	191.3	191.3	191.8	191.8
Fan		193.1	193.8	193.8	194.3	195	194.8	195.2	195.2
Harp	Final tension in	257.2	257.4	257.2	257.2	257	257	257	257
Radiating	cable (15), tons	198.8	198.8	198.9	198.7	199	199	199	199
Fan		204.5	204.5	204.5	204.5	204.4	204.3	204.3	204.3

Table (2): First four natural frequencies for harp and radiating cable stayed bridges, (c .p. s).

Natural frequency number	Cable stayed in harp shape				Cable stayed in radiating shape			
	Single plane of cables		Double plane of cables		Single plane of cables		Double plane of cables	
	Type a	Type c	Type a	Type c	Type a	Type c	Type a	Type c
1	0.18427	0.23310	0.19056	0.18261	0.22336	0.31100	0.18634	0.18187
2	0.34030	0.34253	0.27440	0.22566	0.32134	0.32320	0.31681	0.29767
3	0.34091	0.35448	0.34263	0.35672	0.32154	0.32350	0.33300	0.33507
4	0.37452	0.35453	0.37906	0.35676	0.34691	0.34859	0.33304	0.33510

Table (3): Variations of various responses with pylon height to span ratio (H/L).

Responses	Bridges in harp shape		Bridges in radiating shape		Bridges in fan shape	
	H/L =0.2	H/L=0.5	H/L =0.2	H/L=0.5	H/L =0.2	H/L=0.5
€ for cable element 5	0.33	0.26	0.26	0.22	0.25	0.21
€ for cable element 10	0.41	0.29	0.34	0.33	0.33	0.22
€ for cable element 15	0.49	0.32	0.41	0.40	0.40	0.30
S with case of load 4.	H/25	H/210	H/30	H/270	H/32	H/280
N.F. factor ∂	1.98	1.12	1.53	0.28	1.45	0.26
B.M. factor, μ (%)	4.89	1.5	2.45	1.12	2.4	1.2
Maximum deflection, Δ	L/110	L/400	L/180	L/520	L/170	L/480

Table (4): Statistic analysis for some pylon responses.

response	bridge	Connection	Single plane of cable				Double plane of cable			
			Min.	Max.	Mean	Static	Min.	Max.	Mean	Static
Sway at pylon top (X-axis), cm	Harp	a	0.0	8.56	4.16	4.57	0.0	8.50	4.36	4.57
		c	-6.21	10.3	1.8	2.03	-5.16	9.23	1.78	2.03
	Radiating	a	0.0	12.21	5.22	4.95	0.0	8.97	4.75	4.95
		c	-1.83	5.2	1.73	2.27	-2.08	6.17	2.22	2.27
Horizontal velocity At pylon top m/sec.	Harp	a	-0.30	0.30	0.0	-	0.28	-0.31	0.0	-
		c	0.97	-1.1	0.0	-	0.62	-0.63	0.0	-
	Radiating	a	-0.18	0.20	0.0	-	0.25	-0.28	0.0	-
		c	0.44	0.46	0.0	-	-0.25	0.32	0.0	-
Normal force in pylon at attached point with floor(tons	Harp	a	-1346	-7757	-4519	-4516	-1468	-7569	-4515	-4516
		c	-909	-8029	-4525	-4519	-1719	-7246	-4527	-4519
		a	-1974	-7288	-4800	-4777	-2054	-7484	-4791	-4777
		c	-312	-8944	-4795	-4780	-112	-8416	-4800	-4780
B.M. in pylon at attached point with floor	Harp	a	-2652	3092	196	205	-2298	2878	186	206
		c	3600	-3686	-20	-20	2702	-2750	-21	-21
	Radiating	a	-4054	4776	-85	-78	3633	-3700	-62	-78
		c	1988	-2657	-260	-266	1229	-1882	-270	-266

Table (5): Statistic analysis for some floor beam responses.

response	bridge	Type	Single plane of cable				Double plane of cable			
			Min.	Max.	Mean	Static	Min.	Max.	Mean	Static
Deflection at mid right span (floor beam) (cm)	Harp	a	-22.42	-147.00	-86.16	-89.30	-22.42	-147.00	-86.80	-89.30
	Harp	c	-19.46	-131.66	-87.00	-87.10	-21.42	-144.40	-84.00	-87.10
	Radiating	a	-10.26	-106.00	-58.80	-60.20	-10.26	-106.00	-58.60	-60.20
	Radiating	c	-9.40	-104.00	-55.70	-57.80	-9.40	-104.00	-56.00	-58.20
Velocity in Z-axis at mid floor beam m/sec.	Harp	a	3.40	-3.45	0.008	-	-3.45	3.45	0.008	-
	Harp	c	2.85	-3.15	0.013	-	-3.44	3.44	-0.013	-
	Radiating	a	-2.79	2.91	-.011	-	-2.79	2.91	-0.008	-
	Radiating	c	2.81	-2.64	-0.008	-	-2.81	2.84	-0.007	-
Acceleration in Z-axis at mid beam m/sc2c.	Harp	a	-29.34	30.68	-0.015	-	-26.69	27.43	-0.023	-
	Harp	c	-42.6	43.3	-0.018	-	25.80	-31.00	-0.016	-
	Radiating	a	-26.89	29.84	0.0002	-	-22.80	25.95	0.015	-
	Radiating	c	39.11	-46.83	0.004	-	-24.50	24.50	0.005	-
N.F. at mid floor beam(t)	Harp	a	474	-3022	-1326	-1308	0.0	-2852	-1322	-1308
	Radiating	a	581	-2613	-1058	-1040	286	-2507	-1060	-1040
N.F. at 228 m Floor beam ,t	Harp	a	-338	-5900	-2997	-2992	-723	-5225	-2991	-2992
	Radiating	a	-518	-4239	-1826	-1807	175	-3980	-1824	-1808
B.M. at 228 m beam ,tm	Harp	a	-1674	-11107	-6521	-6648	-1674	-11189	-6553	-6648
	Radiating	a	138	-5238	-2738	-2882	158	-5013	-2798	-2883
S.F. at 228 m beam ,tons	Harp	a	-148	-537	-340	-340	-137	-567	-340	-340
	Radiating	a	7	-443	-236	-240	-11	-477	-239	-240

Table (6): Statistic analysis for some cable responses.

response	bridge	Connection	Single plane of cable				Double plane of cable			
			Min.	Max.	Mean	Static	Min.	Max.	Mean	Static
Horizontal displacement at mid upper cables, cm	Harp	a	-6.22	135.7	69.5	71	32.3	108.4	70.13	71
	Harp	c	-23.45	153	63.5	68.1	-56.68	171.3	61.7	68.1
	Radiating	a	-182.8	288	61.6	78	-172	280	62.4	78
	Radiating	c	-126	246	60.6	75.3	-121.7	243	59.5	75.3
Horizontal velocity at mid upper cables, m/sec.	Harp	a	-3.02	3.36	0.0013	-	2.1	-2.21	-0.009	-
	Harp	c	3.71	-3.98	-0.006	-	-3.93	4.22	-0.002	-
	Radiating	a	-7.86	8.34	-0.006	-	-7.09	7.68	-.002	-
	Radiating	c	-5.59	6.22	-0.005	-	6.02	-6.09	0.002	-
Horizontal acceleration mid upper cables, m/sec.2	Harp	a	231	-234	-0.01	-	-155	166	-0.03	-
	Harp	c	-211	225	-0.009	-	176	-193	0.03	-
	Radiating	a	130	-151	0.014	-	108	-116	0.004	-
	Radiating	c	-128	133	0.026	-	86	-94	-.027	-
Final tensions in cable number (5) (tons)	Harp	a	92.4	299	198.2	198.2	97	299	198.3	198.2
	Harp	c	103	297	196	198.2	104	297	196	198.2
	Radiating	a	85.3	261	173	171	85.4	260	171.5	171
	Radiating	c	87.4	254	170	171	88	253	173	171.2
Final tensions in cable number (10) (tons)	Harp	a	110	354	227	228	111	354	226	228
	Harp	c	116	351	228	228	116	351	228	228
	Radiating	a	88	290	186	189	89	291	187	189
	Radiating	c	94	291	198	190	94	291	196	190

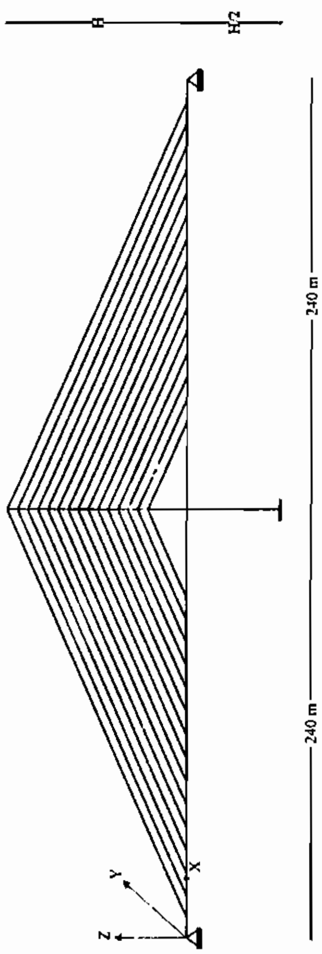


Fig.(1-a): Cable stayed bridge with single plane of cables (harp shape).

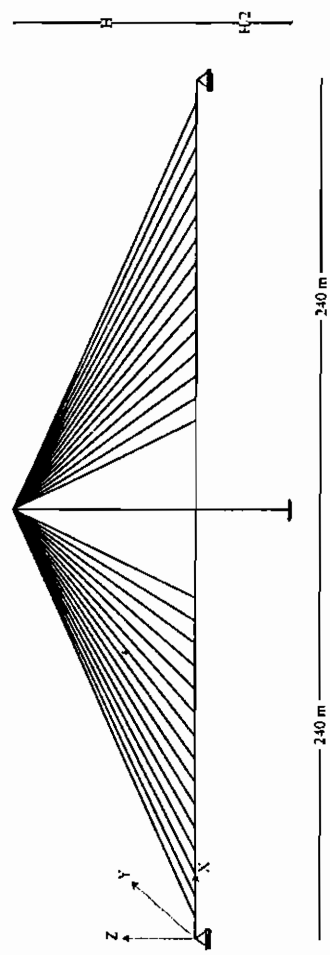


Fig.(1-b): Cable stayed bridge with single plane of cables (radiating shape).

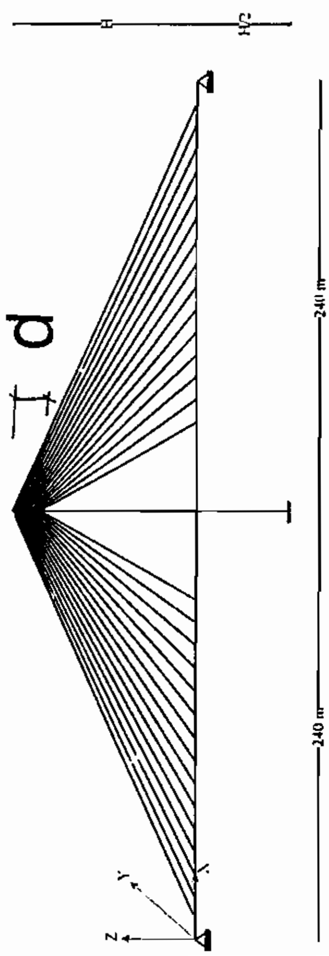


Fig.(1-c): Cable stayed bridge with single plane of cables (fan shape).

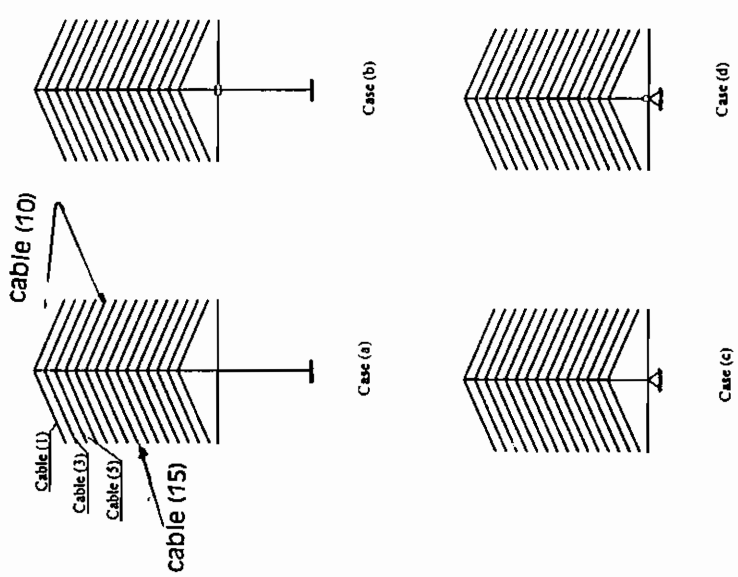


Fig.(2): Connection types between pylons and floor beams.

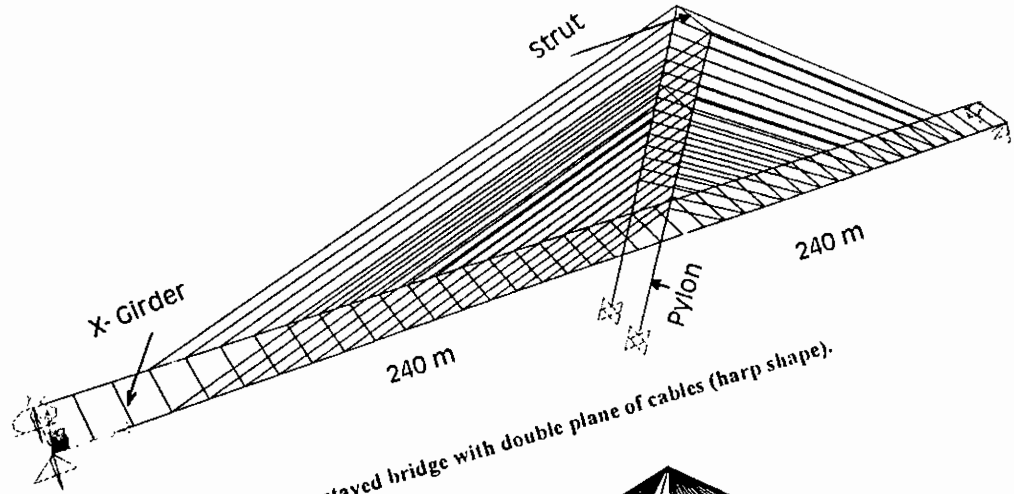


Fig.(3-a): Cable stayed bridge with double plane of cables (harp shape).

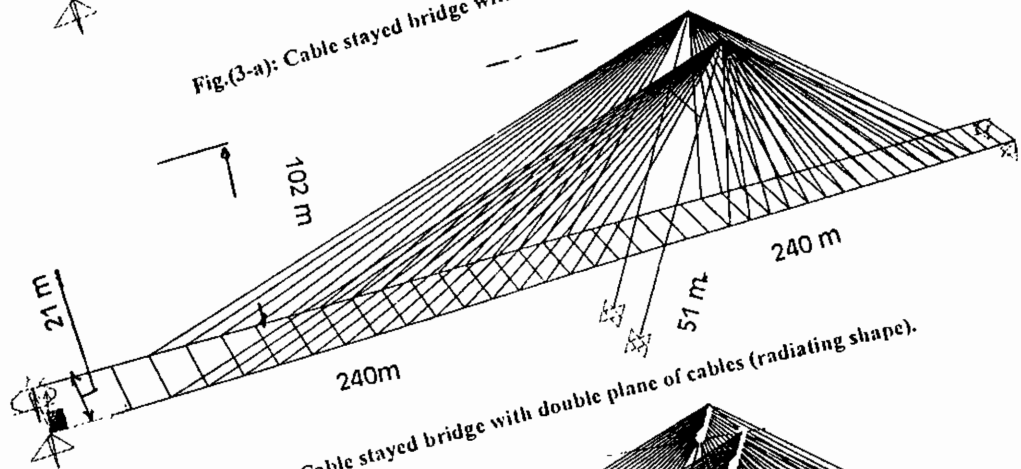


Fig.(3-b): Cable stayed bridge with double plane of cables (radiating shape).

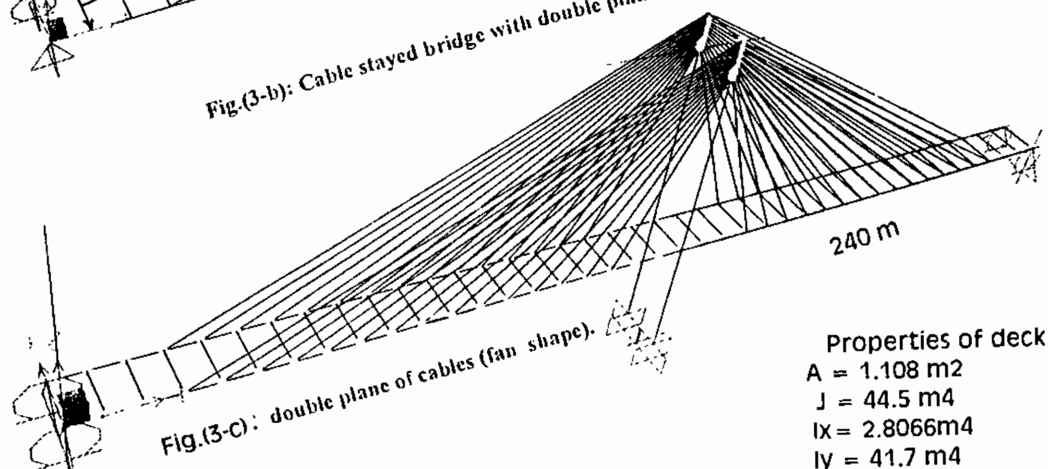


Fig.(3-C) : double plane of cables (fan shape).

Properties of deck
A = 1.108 m2
J = 44.5 m4
Ix = 2.8066m4
Iy = 41.7 m4
E = 2100 t/cm2

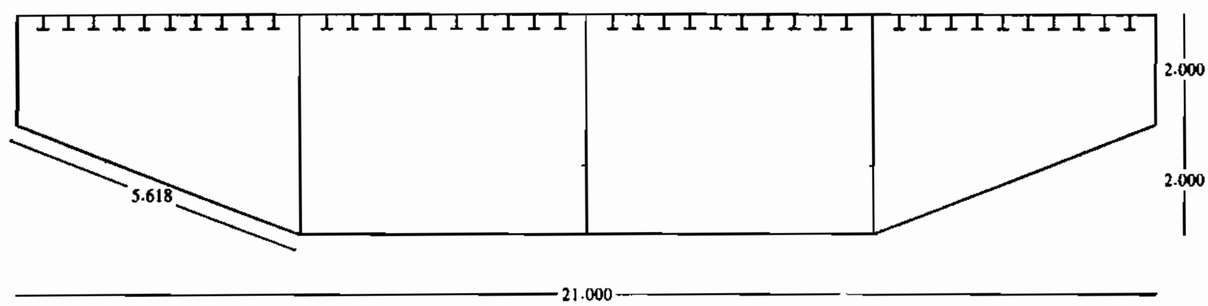


Fig.(4): Cross section of deck floor.

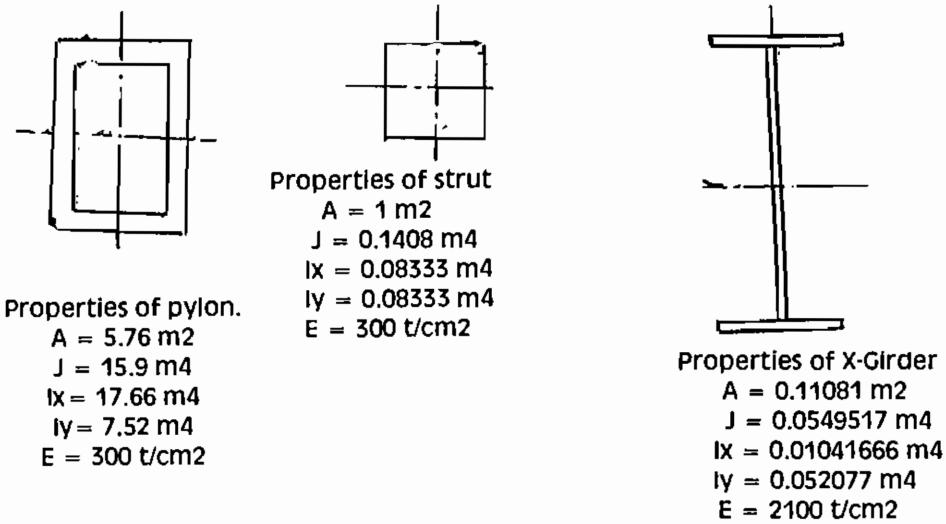


Fig.(5) : Cross section of pylon , strut , and X-Girder

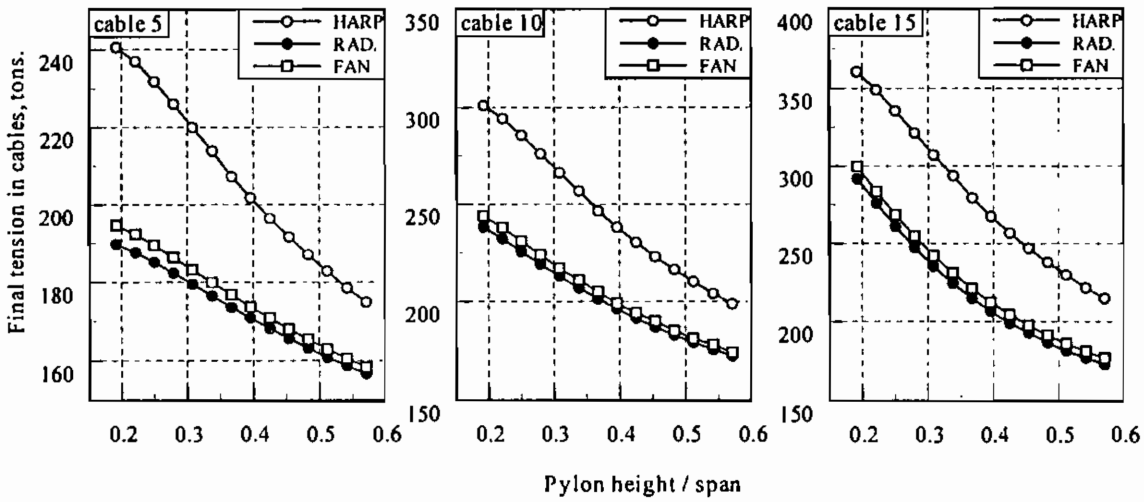


Fig.(6): Variation of tension in some cables (type a and load 1).

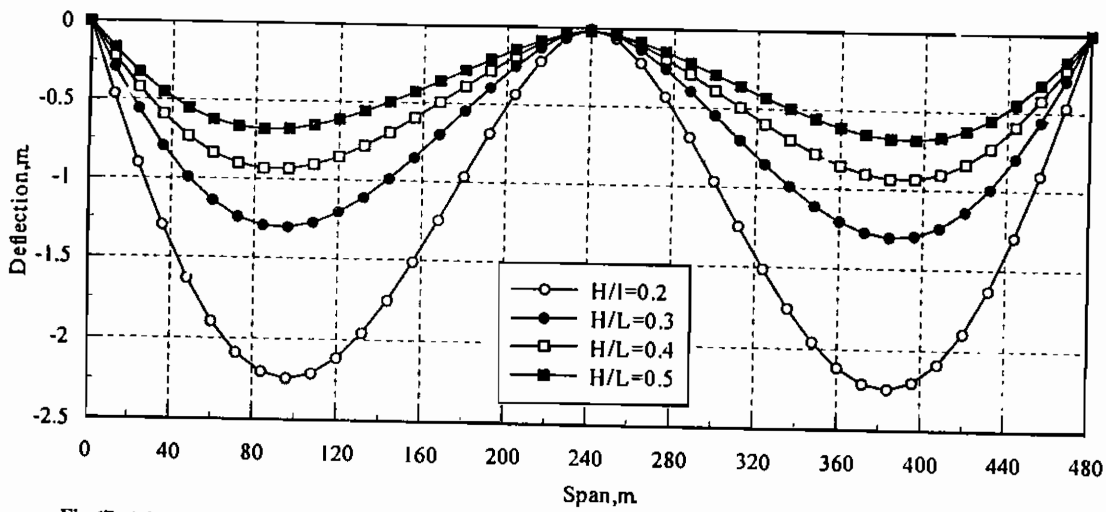


Fig.(7-a):Variation of floor beam deflection, m (harp shape, type a, and load 1).

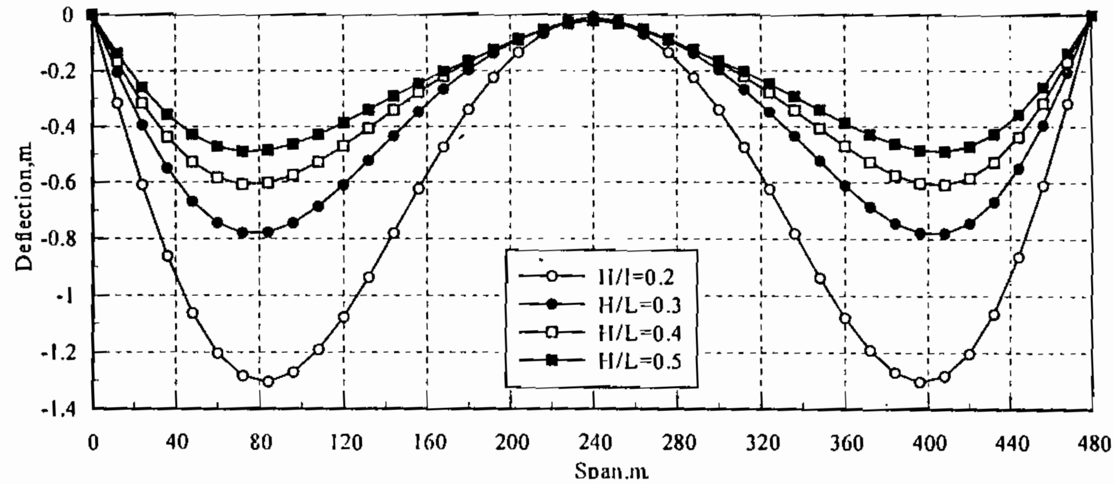


Fig.(7-b):Variation of floor beam deflection, m (radiating shape, type a, and load 1).

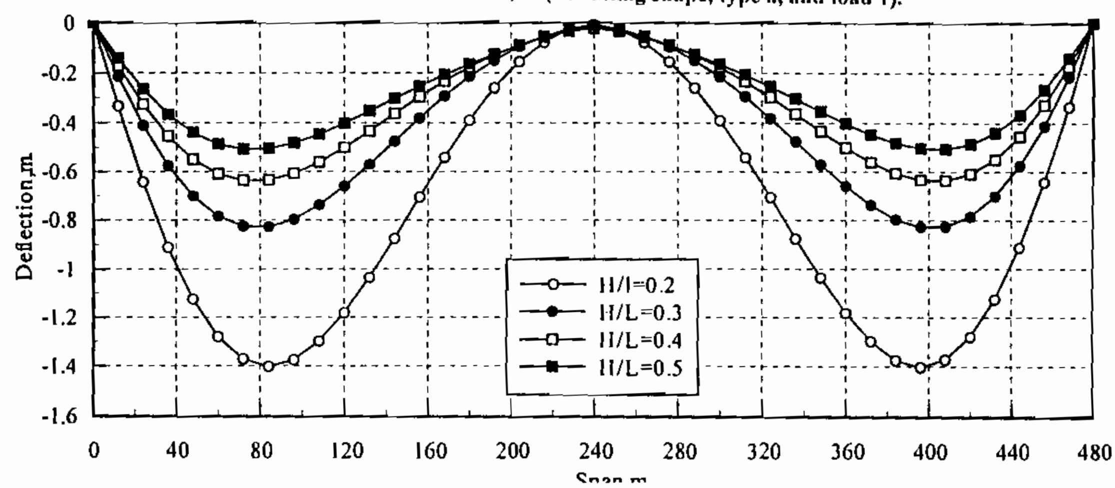


Fig.(7-c):Variation of floor beam deflection, m (fan shape, type a, and load 1).

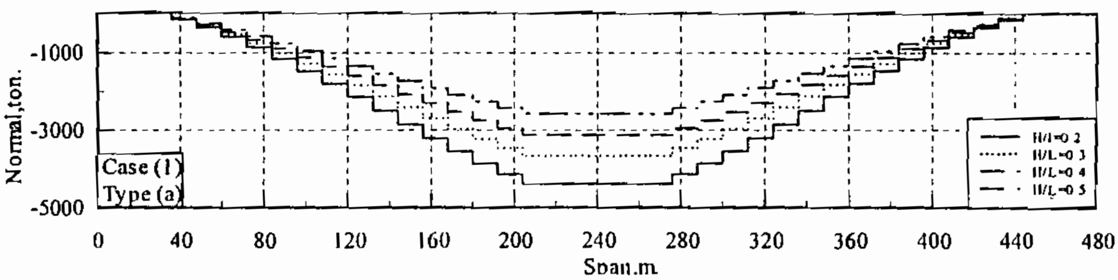


Fig.(8-a):Variation of normal force in floor beam, tons (harp, type a, and load 1).

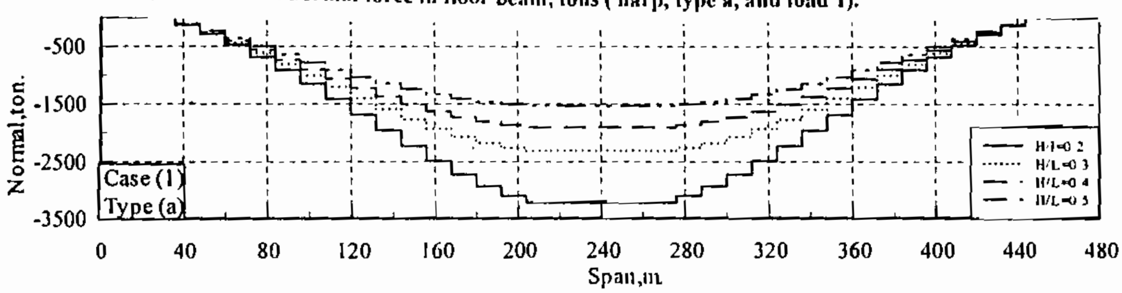


Fig.(8-b):Variation of normal force in floor beam, tons (radiating, type a, and load 1).

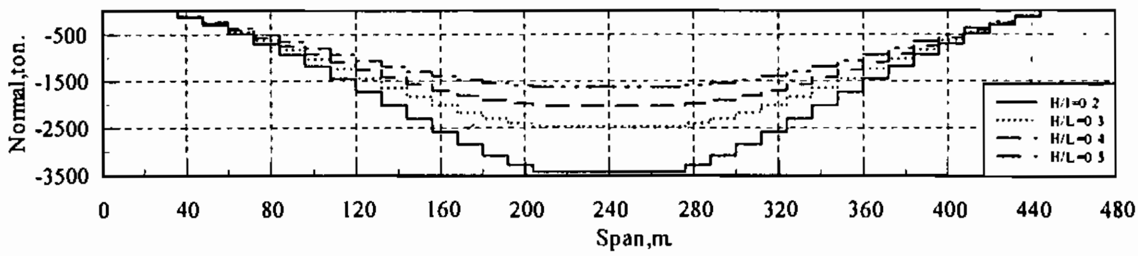


Fig.(8-c):Variation of normal force in floor beam, tons (fan, type a, and load 1).

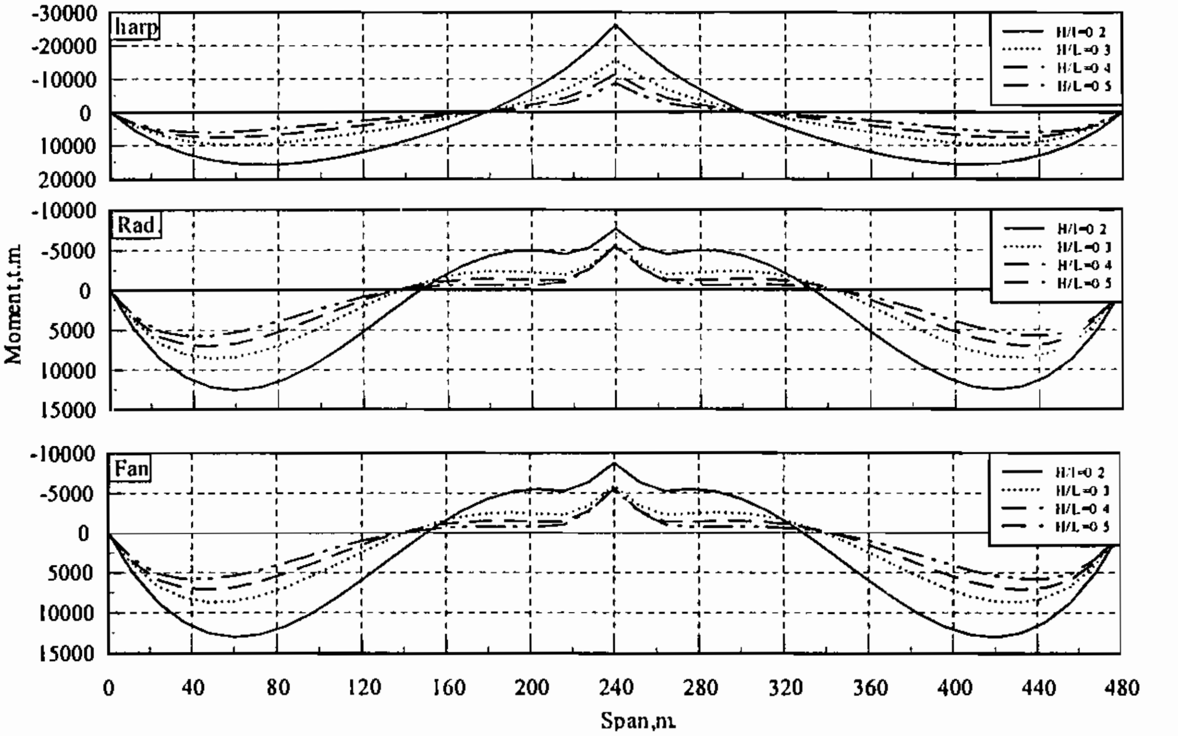
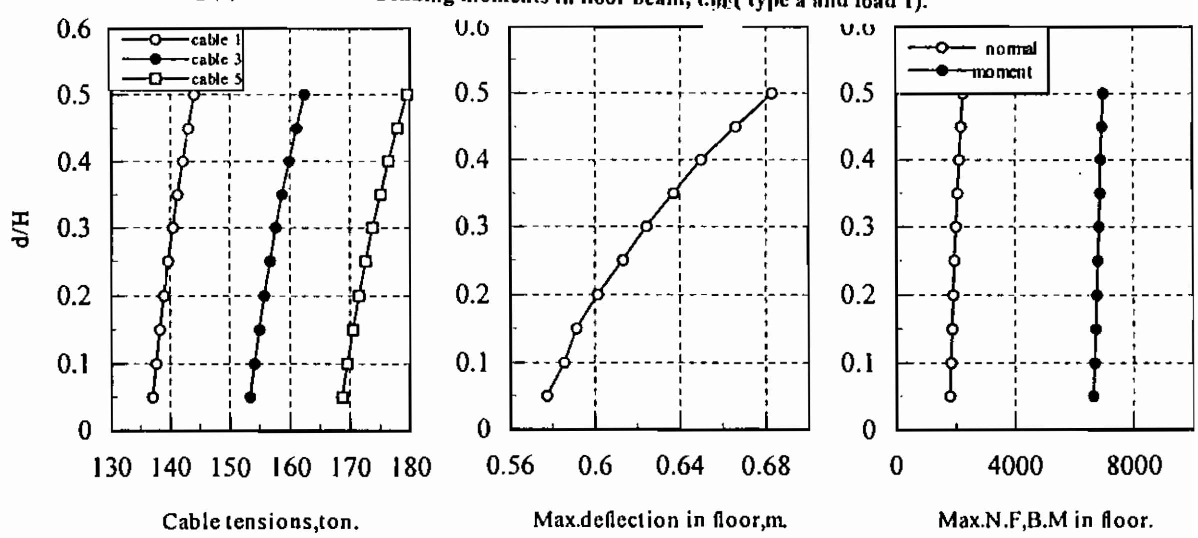


Fig.(9): Variation of bending moments in floor beam, t.m.(type a and load 1).



Fig(10):Variation of fan shape responces with (d/H).

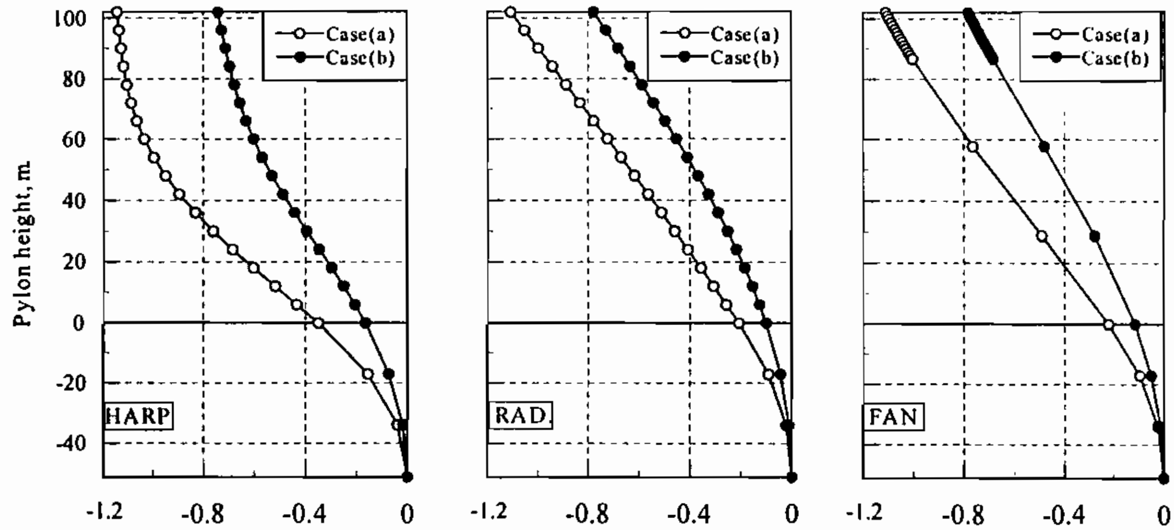


Fig.(11-a): Longitudinal sway (in x-axis) along pylon height , m (type a and load (2)

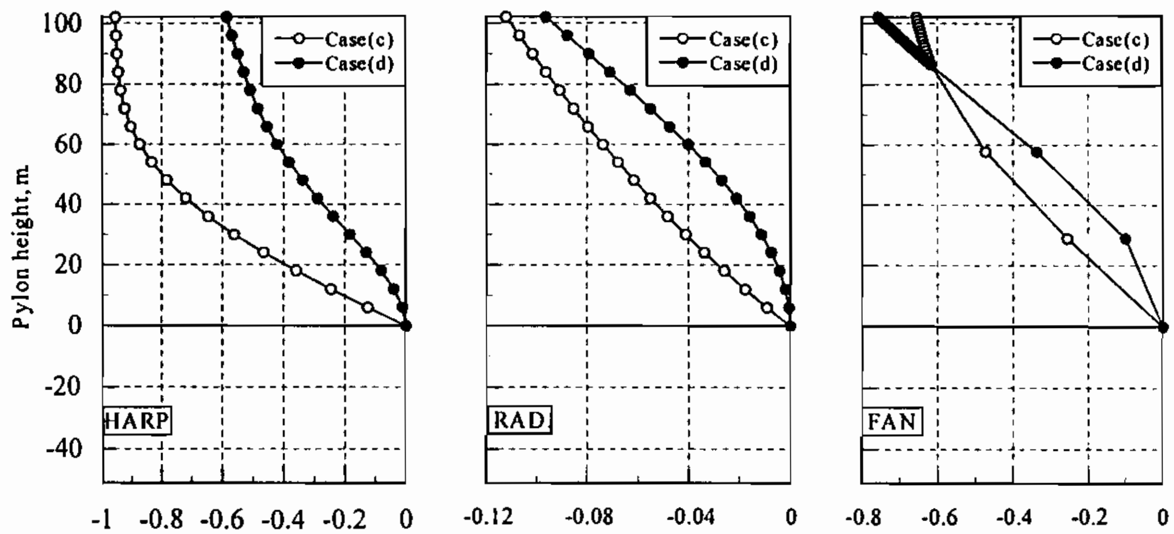


Fig.(11-b): Longitudinal sway (in x-axis) along pylon height , m (type a and load 2

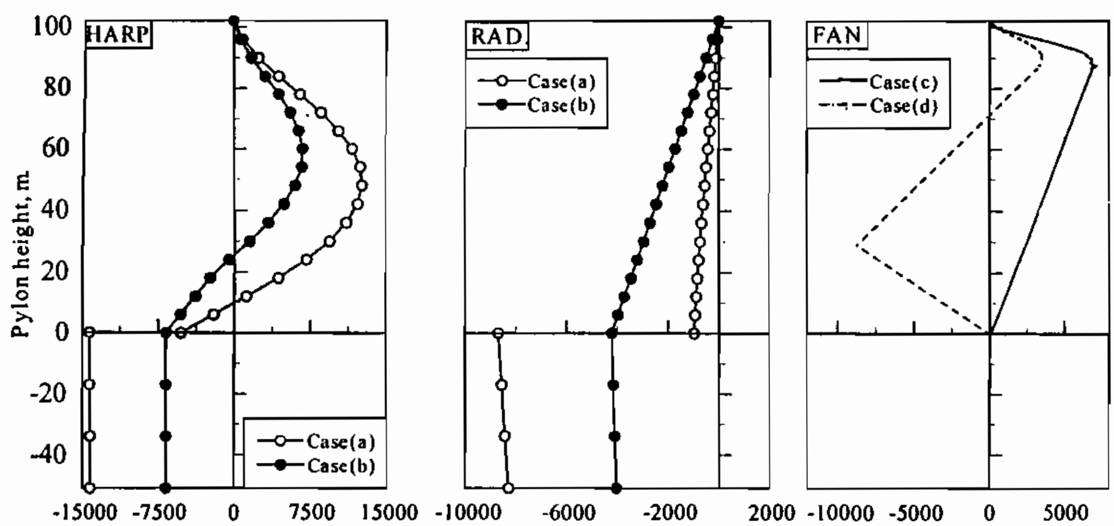
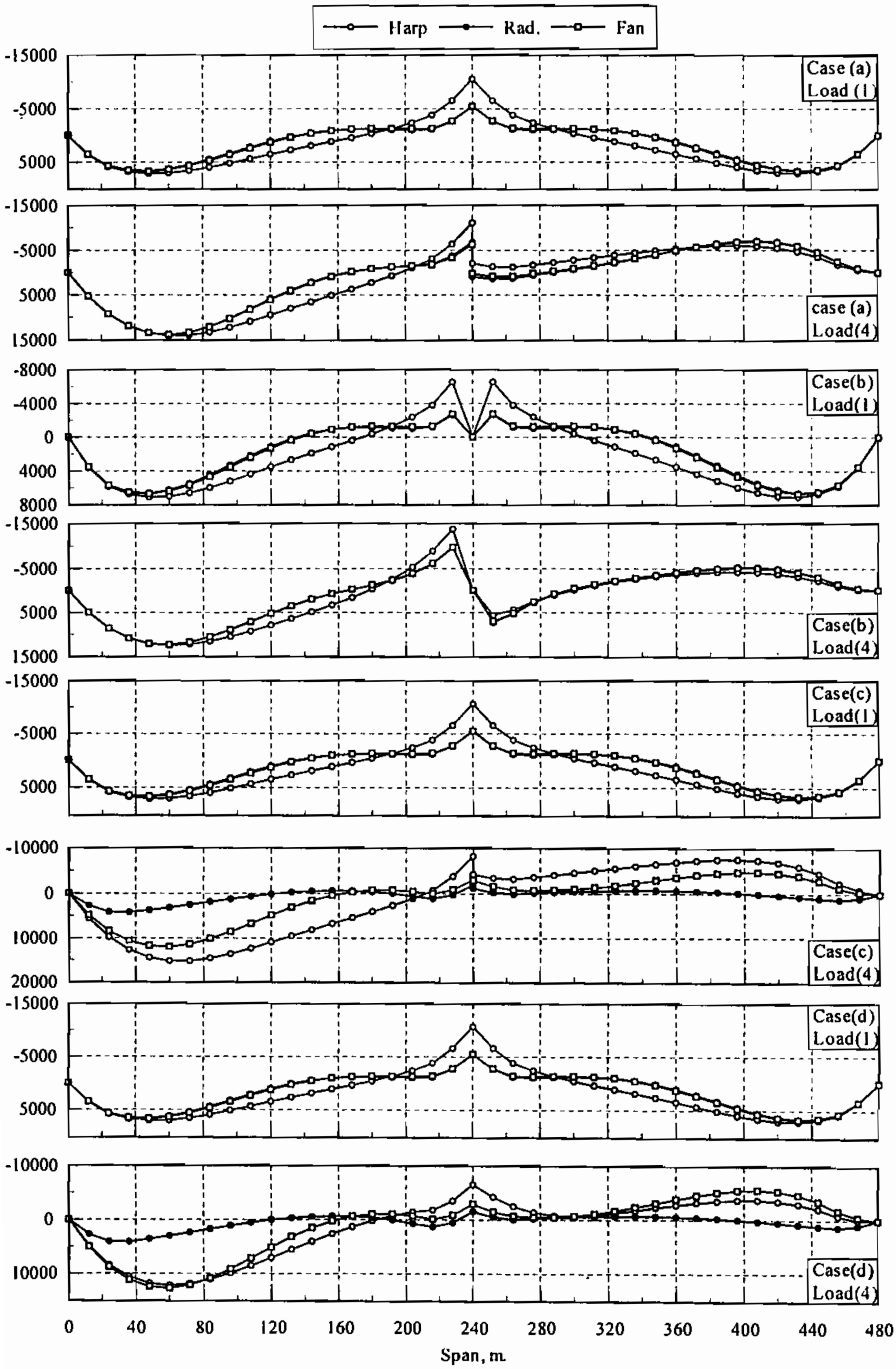
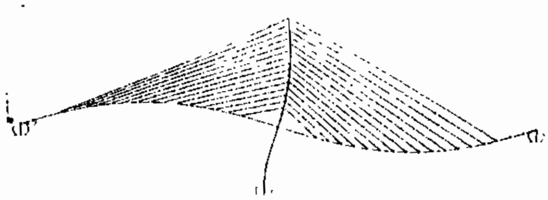


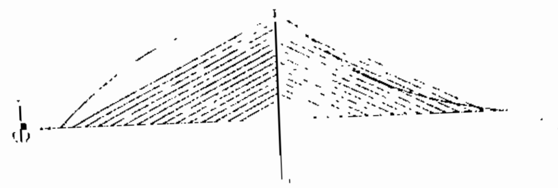
Fig.(11-c): Bending moment along pylon height , t.m (type a and load 1)



Fig(14): Variation of bending moment in floor beam,tons.

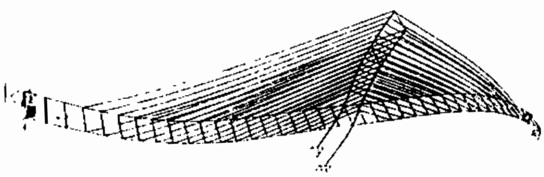


Mode 1
0.18427 (c.p.s)

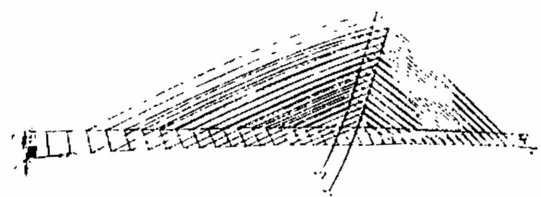


Mode 2
0.34030 (c.p.s)

Single plane of cables, connection type a.

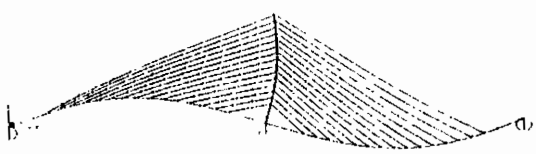


Mode 1
0.19056 (c.p.s)

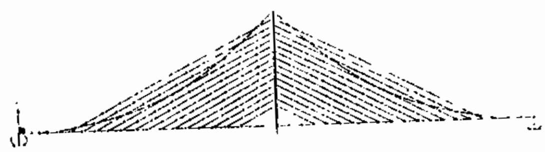


Mode 2
0.27440 (c.p.s)

Double plane of cables, connection type a.

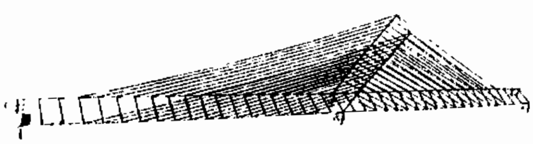


Mode 1
0.23310 (c.p.s)

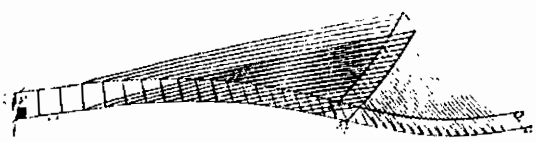


Mode 2
0.34253 (c.p.s)

Single plane of cables, connection type c.



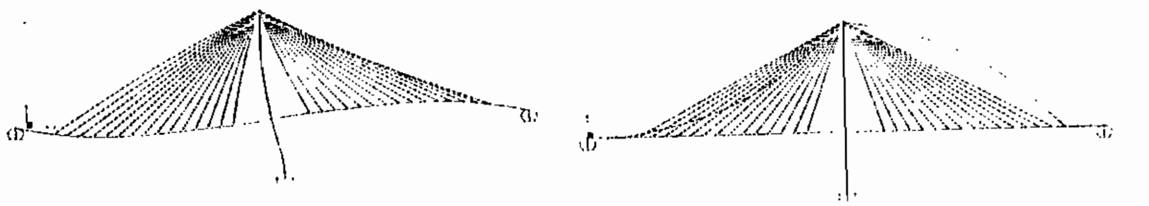
Mode 1
0.18261 (c.p.s)



Mode 2
0.22566 (c.p.s)

Double plane of cables, connection type c.

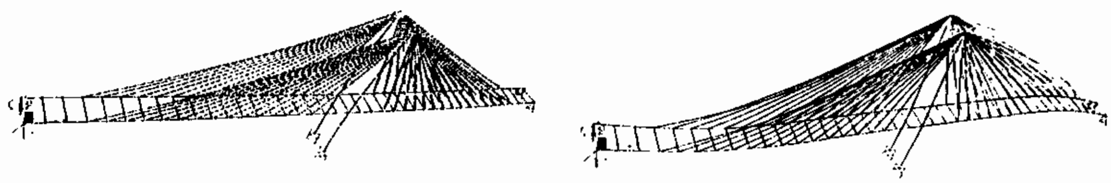
Fig.(15): First and second natural frequencies and corresponding modes(harp shape).



Mode 1
0.22336 (c.p.s)

Mode 2
0.32134 (c.p.s)

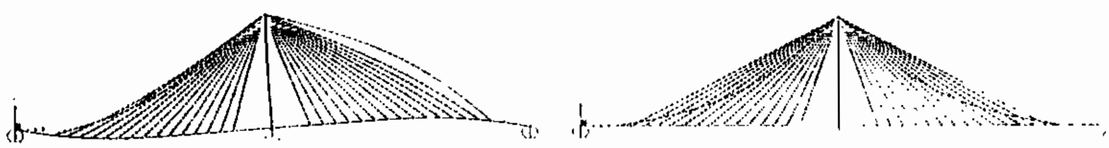
Single plane of cables, connection type a.



Mode 1
0.18634 (c.p.s)

Mode 2
0.31681(c.p.s)

Double plane of cables, connection type a.



Mode 1
0.31100 (c.p.s)

Mode 2
0.32320(c.p.s)

Single plane of cables, connection type c.

Mode 1
0.18187 (c.p.s)

Mode 2
0.29767 (c.p.s)

Double plane of cables, connection type c.

Fig.(16):First and second natural frequencies and corresponding modes(radiating).

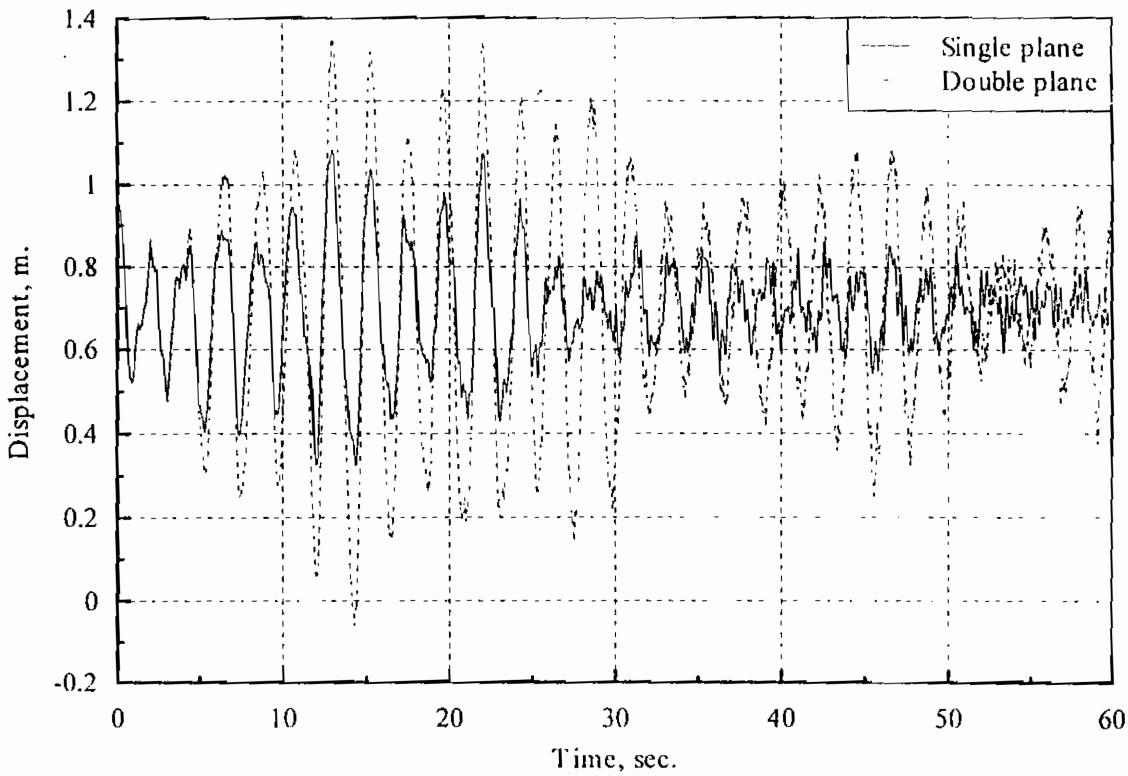


Fig.(17): Displacement time history in X-axis at mid upper cable in harp shape.

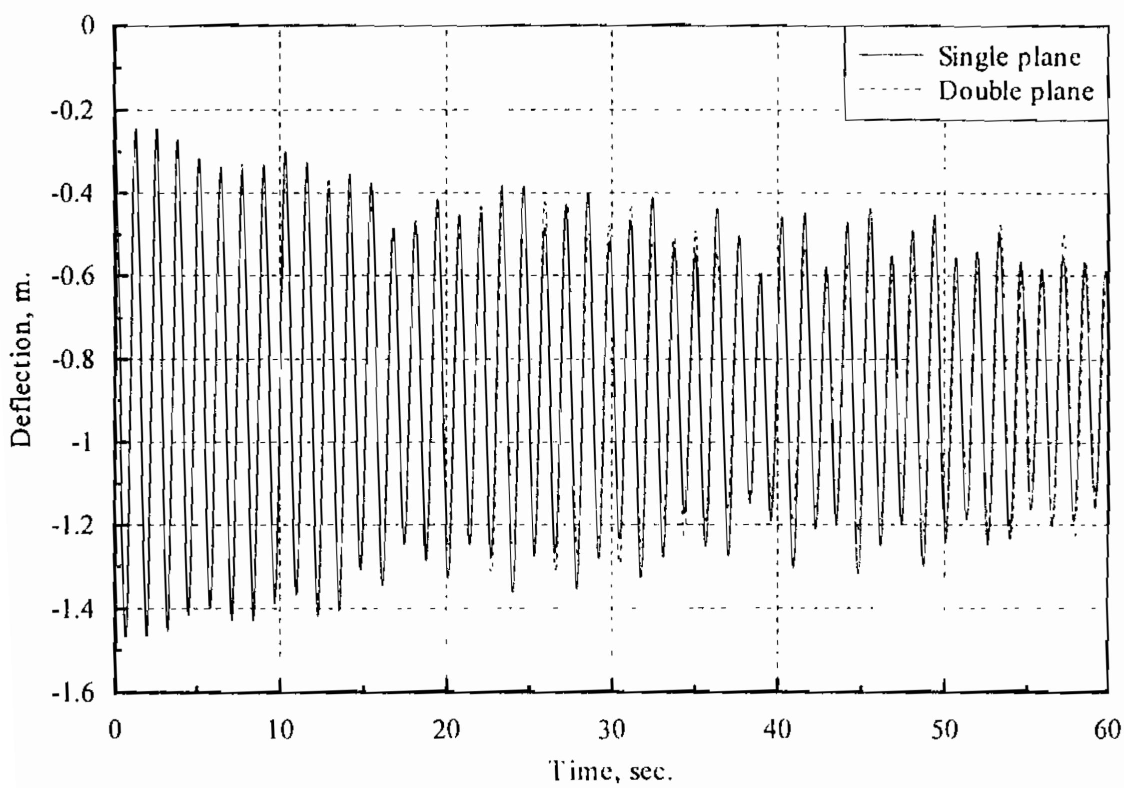


Fig.(18): Deflection time history at mid floor beam in harp shape.

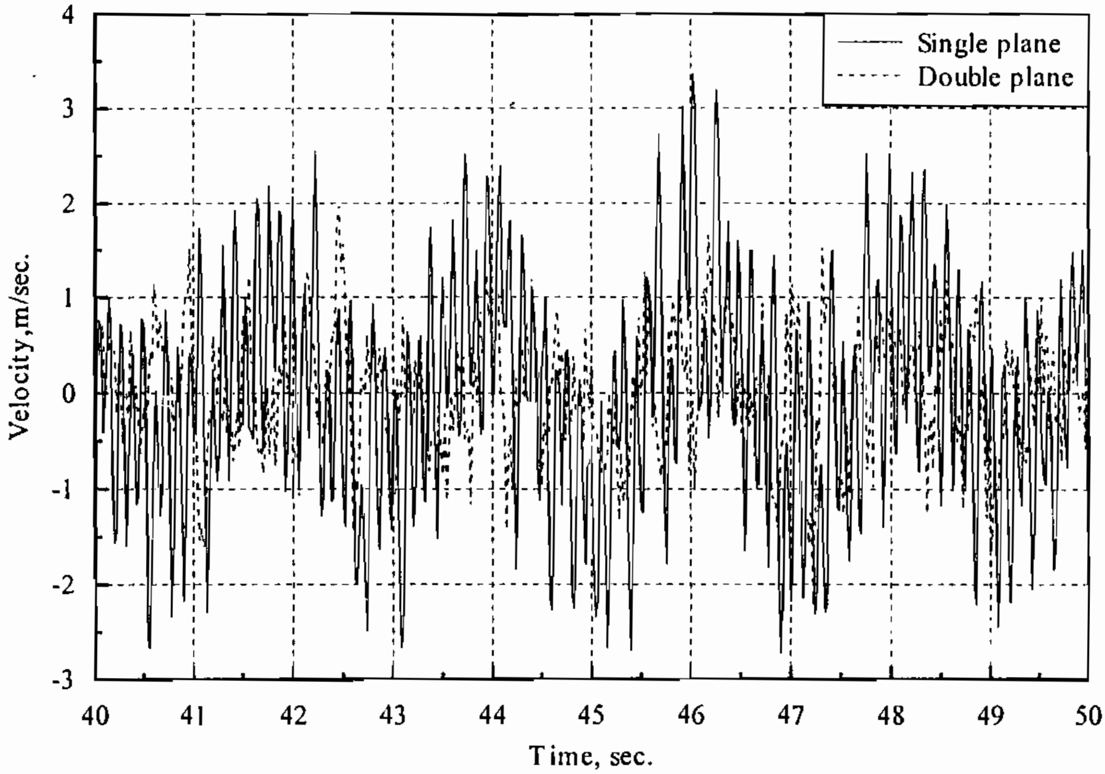


Fig.(19): Velocity time history in X-axis at mid upper eable in harp shape.

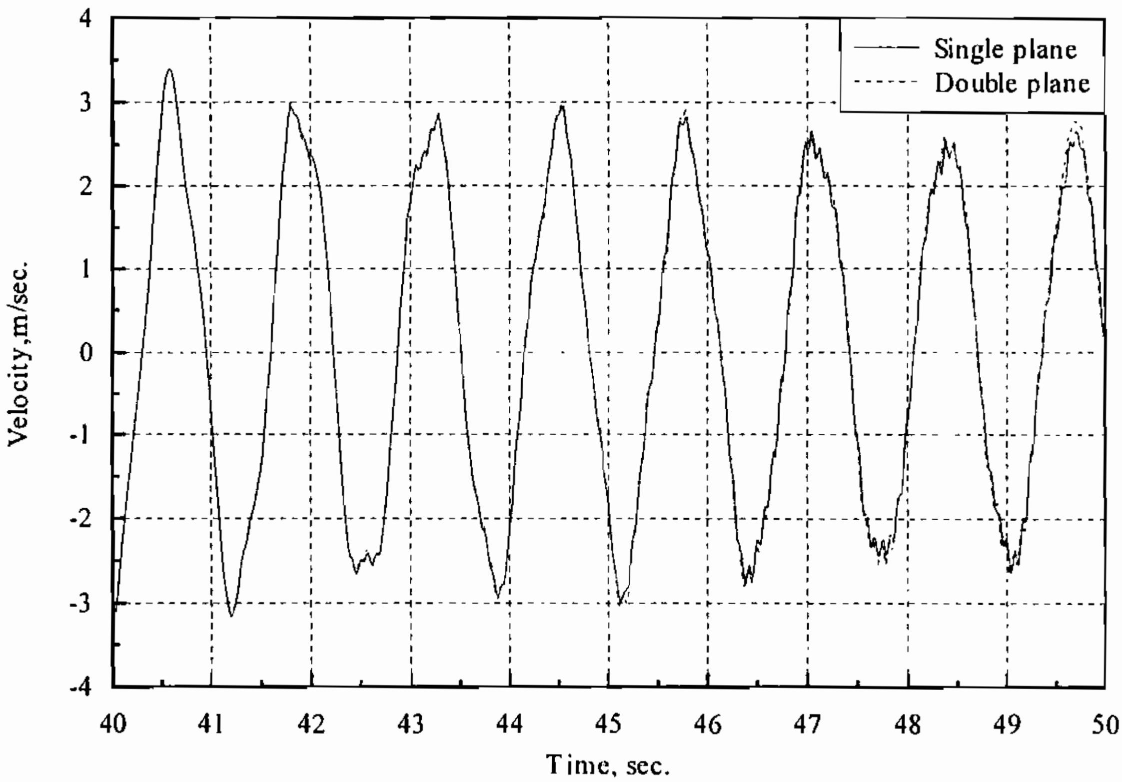


Fig.(20): Velocity time history at mid floor beam in Z-direction in harp shape.

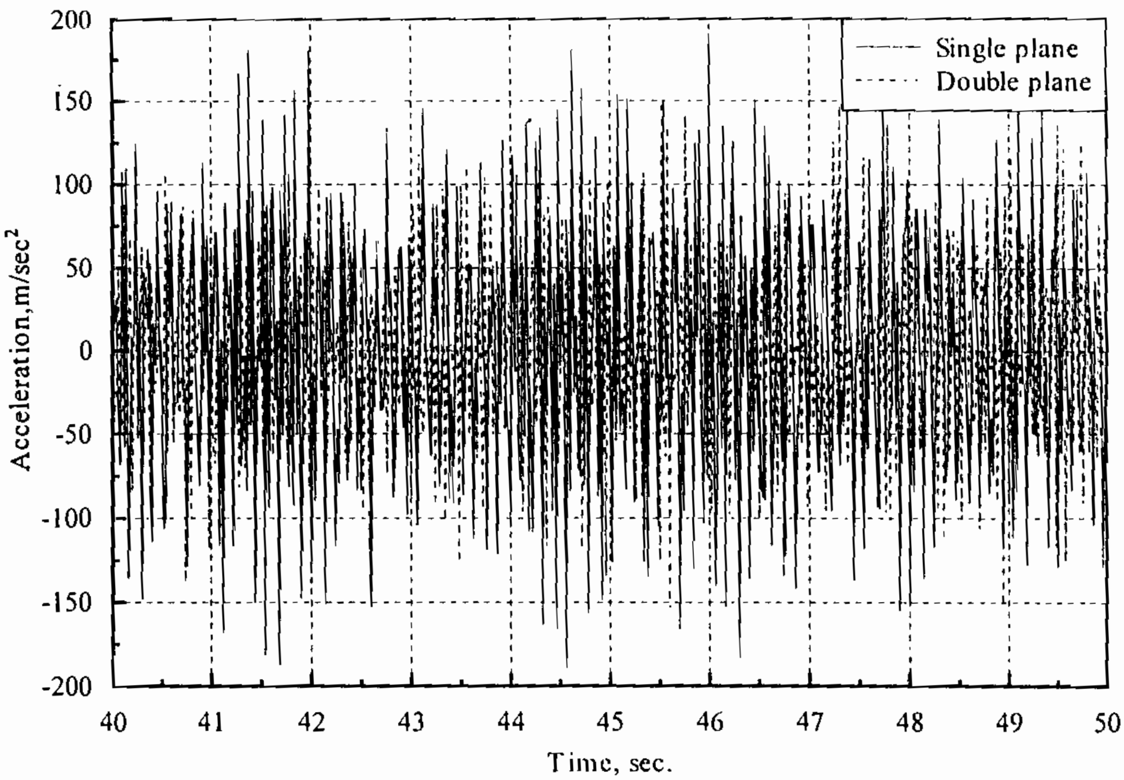


Fig.(21): Acceleration time history in X-axis at mid upper cable in harp shape.

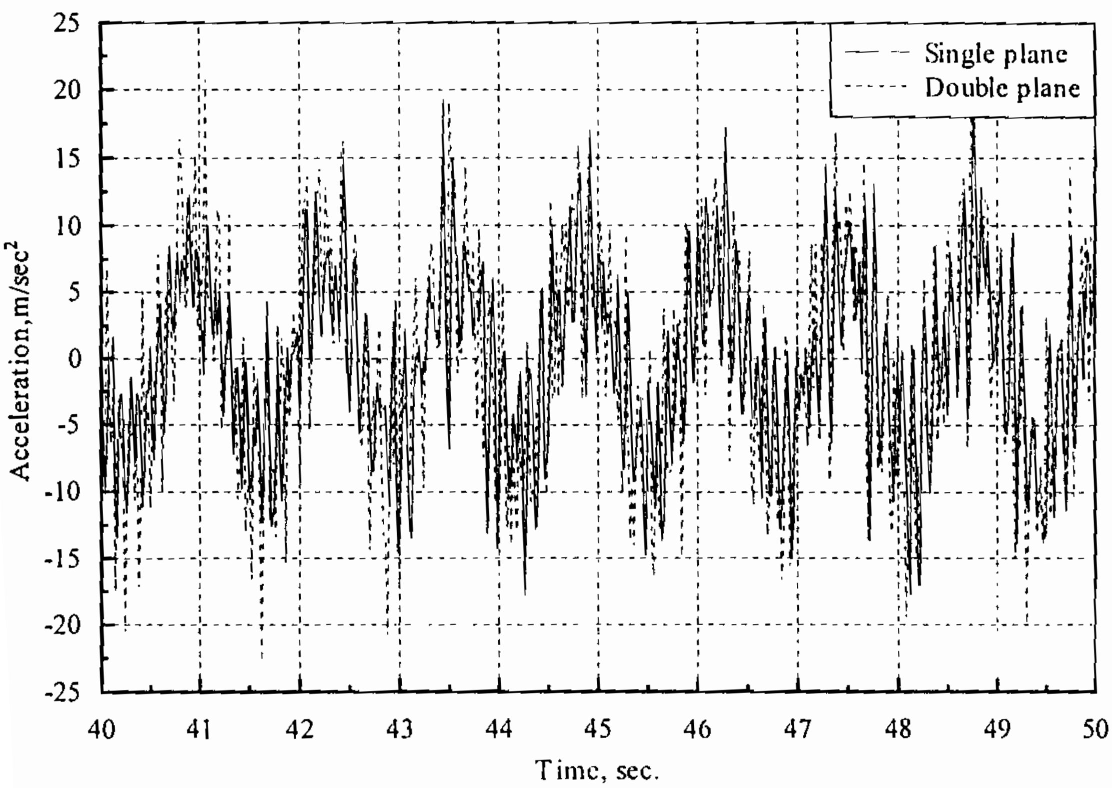
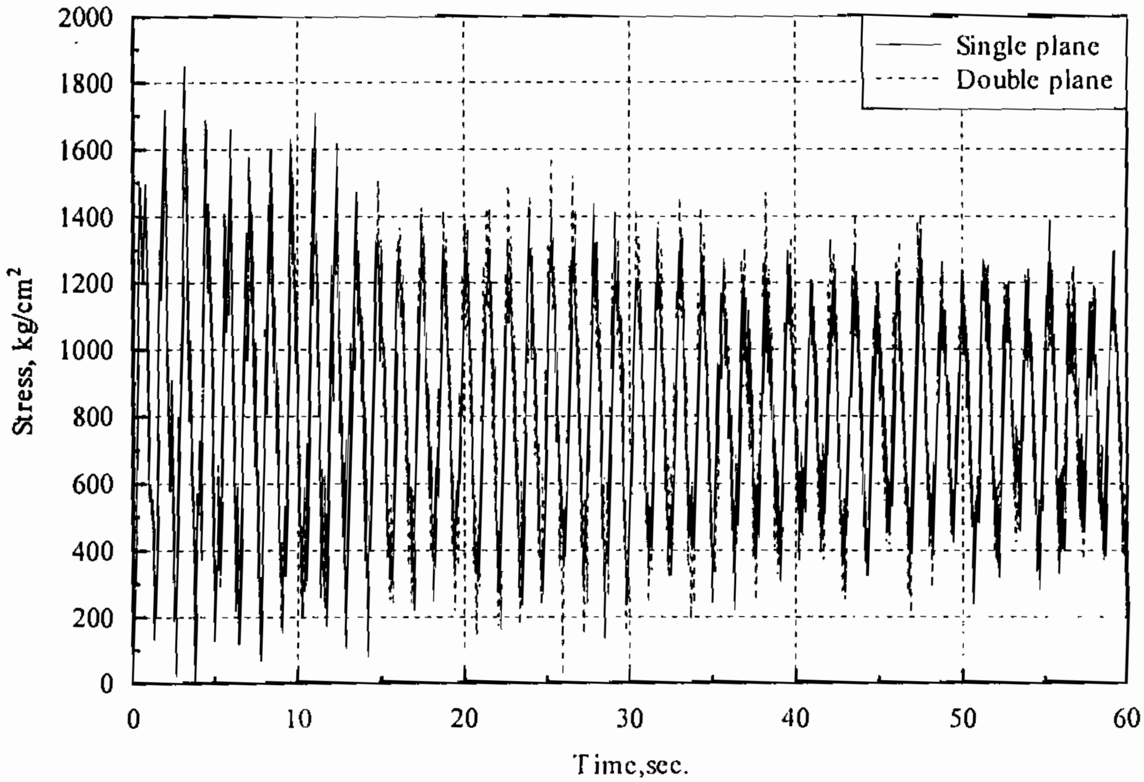
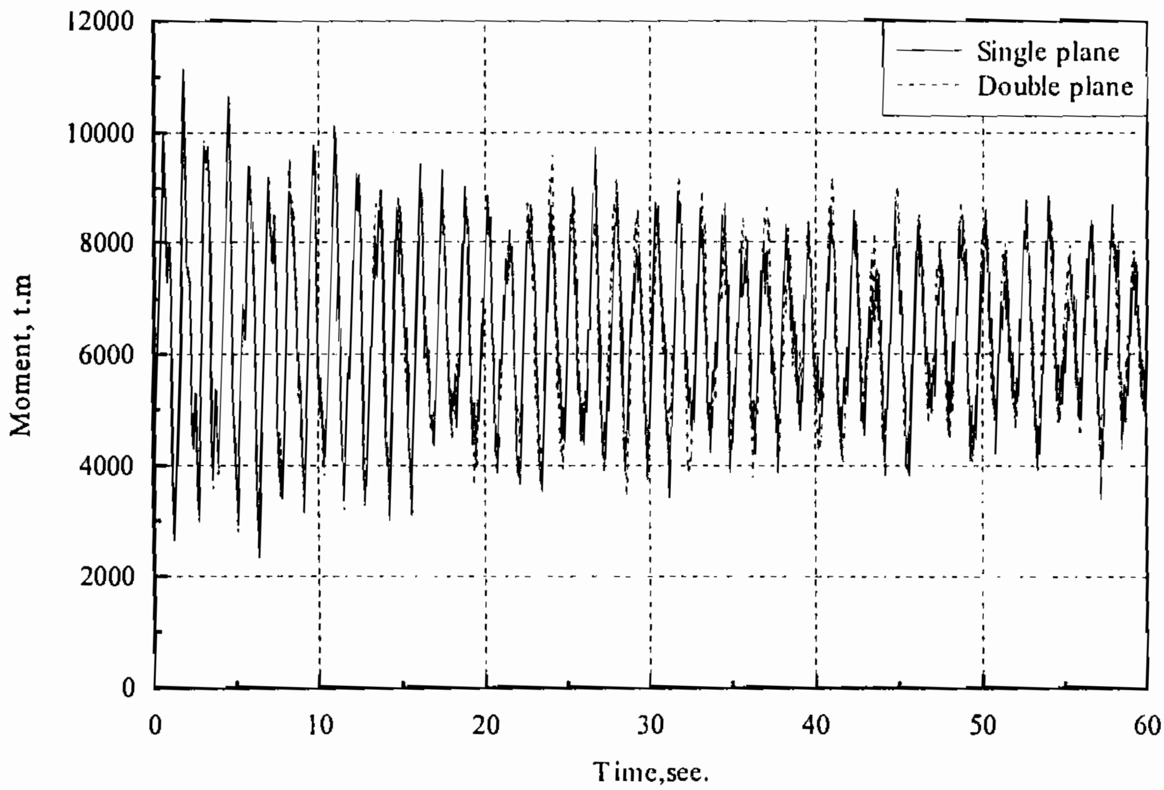


Fig.(22): Acceleration time history at mid floor beam in Z-direction in harp shape.



Fig(23): Dynamic stress time history at mid floor beam in harp shape.



Fig(24): Dynamic bending moment at 228 m from left support in harp shape.