THE INFLUENCE OF PHASE-DIFFERENCE EFFECTS ON EARTHQUAKE RESPONSE OF CABLE-STAYED BRIDGES

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ABSTRACT

In this paper, a model of cable-stayed bridges for earthquake response analysis is established. The earthquake response analysis is performed by using a large-stiffness technique with MSC/NASTRAN . The influence of phase-difference effects on the earthquake response is discussed.

INTRODUCTION

As cable-stayed bridges are increasing in popularity , more concerns are raised about their seismic behavior. Their seismic response under multiple- support excitation has different characteristics from that under uniform input. Lessons in the past earthquake show that the effect of a travelling wave seems to be a main cause of damaged or failed bridges . As the span length of cable-stayed bridges increases, this influence naturally becomes more obvious and significant.

In general, the correlation of the motion at the support point is very complicated, particularly in the long-span bridges. Marked differences in amplitude as well as in phase could occur . To describe these complicated motions, such as the support point load input , there are some approximate approaches, such as the approach based on stochastic process theory, the approach by making use of the recorded earthquake records of synchronized, closed-spaced arrays, et al. One popular approach is the travelling wave approach. In this approach , a constant value of wave propagation is assigned to the entire seismic disturbance. Despite such simplification, the researches based on this approach could throw some light on the effect of seismic wave propagation on the response of long-span bridges.

In this study, earthquake wave input is based on travelling wave approach . MSC/NASTRAN is used to model cable-stayed bridges, and to perform the seismic response analysis.

THE MODEL

Fig. 1 show the model for dynamic analysis in this study. The deck is supported by cables, rollers at abutments, and elastic links at towers. The towers are rigid at their base.

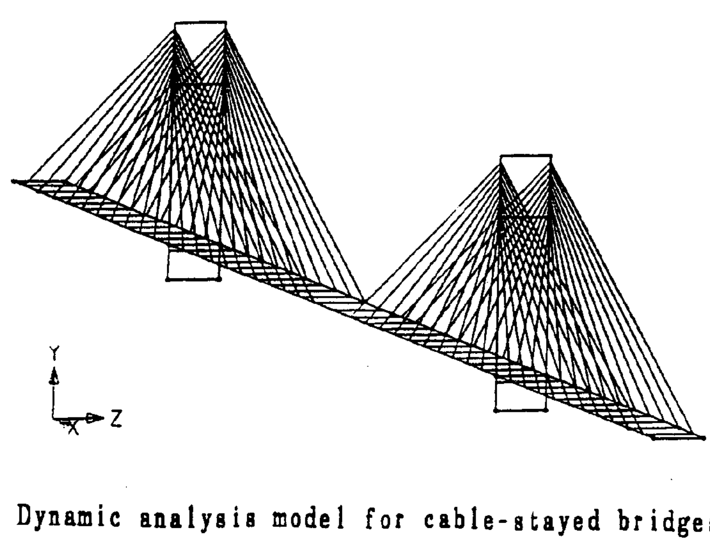

Fig. 1 Dynamic analysis model for cable-stayed bridges

DYNAMIC CHARECTERISTICS

Mode analysis and seismic response analysis are performed by using MSC/NASTRAN at a power station RISC/6000. The analysis results show the following dynamic characteristics for cable-stayed bridges.

1. It has a pure vertical vibration mode.
2. Longitudinal vibration is coupled with vertical vibration .
3. Lateral vibration is independent from the longitudial and vertical vibrations, but is coupled with twisting vibration.
4. Tower vibration are coupled with deck vibration in longitudinal and vertical directions . In lateral direction the coupling relation depends on the way the deck links at towers.

SEISMIC RESPONSE UNDER TRAVELLING WAVE

Seismic response under a travelling wave is performed by using the large-stiffness technique with the direct transient response analysis method. The bridge is subjected to a longitudinal vibration earthquake wave vertical vibration earthquake wave lateral vibration earthquake wave separately , and subject to 3D earthquake wave simulteneously with no time delay and with time delays 0. 5 , 1. 0, 2. 0 second , i. e. the wave propagation velocity 520 m/s, 260 m/s, 130 m/s. The following subjects are studied.

1. Travelling wave effect of cable-stayed bridge under longitudial vibration wave
2. Travelling wave effect of cable-stayed bridge under vertical vibration wave
3. Travelling wave effect of cable-stayed bridge under lateral vibration wave
4. Travelling wave effect of cable- stayed bridge under 3D vibration wave.

Table 1 to table 3 shows the variations in different response quantities of the bridge as a function of the time delay between towers. Fig. 2 to Fig. 7 show the difference of seismic response under uniform input and under input with phase-difference. If the wave propagation velocity is not less than 130 m/s , it is found that:

1. A time delay in the longitudinal vibration wave makes the longitudinal displacement response of both the towers and the deck decrease, and makes the vertical displacement response of the deck increase . But the augmentation do not always increase as the time delay increase.
2. A time delay in the vertical vibration wave makes the longitudinal response as well as vertical response significantly

increase. But they do not always increase as the time delay increase. They seem to change periodically.

3. A time delay in the lateral vibration wave has a less pronounced influence on the bridge response. Particularly when the deck free at the tower or there is elastic link (such as springs with k = 1.0e-2 t/m) between the towers and the deck. In this case, the coupling relations between the towers or between the deck and the towers are little or weak.

4. When longitudinal and vertical earthquake waves are applied simultaneous to the bridge, the time delay makes longitudinal response increase at first , and then decrease , makes the vertical response of the deck increase. In this paper only the longitudinal and the vertical wave phase difference are considered because the lateral response is independent from them and the time delay has less influence.

Table 1 Travelling wave effect of longitudinal vibration wave

time delay	tower disp		deck disp		tower stress		deck stress	
	x 1	x 2	x	y	moment	stress	moment	stress
0 s	23.7	23.9	23.2	0.52	4.4E5	1.45E3	7.5E3	1.6E2
0.5 s	22.6	22.8	22.2	7.8	3.9E5	1.28E3	5.6E4	1.5E3
1 s	20.2	20.5	19.8	10.5	3.5E5	2.4E3	6.7E4	2.05E3
2 s	14.2	14.3	14.	6.9	2.8E5	1.7E3	5E4	1.9E3

Table 2 Travelling wave effect of vertical vibration wave

time delay	tower disp		deck disp		tower stress		deck stress	
	x 1	x 2	x	y	moment	stress	moment	stress
0 s	6.5	6.5	7E-4	43.	2.05E5	7.9E3	2E5	3.6E2
0.5 s	14.	13.	12.	55.	3.2E5	1.09E4	2.1E5	6.2E2
1 s	29.4	29.2	28.2	70.	7E5	1.25E4	3.6E5	9.1E2
2 s	19.	21.	8.6	68.5	5.7E5	1.2E4	3.8E5	2.4E3

Table 3 Travelling wave effect of longitudinal and vertical vibration wave.

time delay	tower disp		deck disp		tower stress		deck stress	
	x 1	x 2	x	y	moment	stress	moment	stress
0 s	23.5	23.5	23.2	44	4.4E5	8E3	2E5	3.05E2
0.5 s	29	28	28.1	49.5	4.95E5	1.09E4	2.27E5	1.93E3
1 s	38	43	40	67	8.7E5	1.15E4	3.3E5	2.8E3
2 s	23	27	18.5	72	7.3E5	2.3E3	3.95E5	2.3E3

note: units in above tables

displacement: cm , moment: n · m, stress: kpa

x represents the longitudinal direction , y represents the vertical direction. all the above values are maximum response values

CONCLUSIONS

1. The travelling wave effet has a significant influence on the seismic response of cable-stayed bridges
2. The phase-difference of the lateral vibration wave has less pronounced effet on the seismic response of cable-stayed bridges .
3. The phase-difference of the vertical vibration wave has most pronounced effet on the seismic response of cable-stayed bridges . It makes the response increase a lot.
4. The phase-difference of the longitudinal vibration wave also has a pronounced effet on the seismic response of cable-stayed bridges. It makes the tower response decrease , and the deck response increase.

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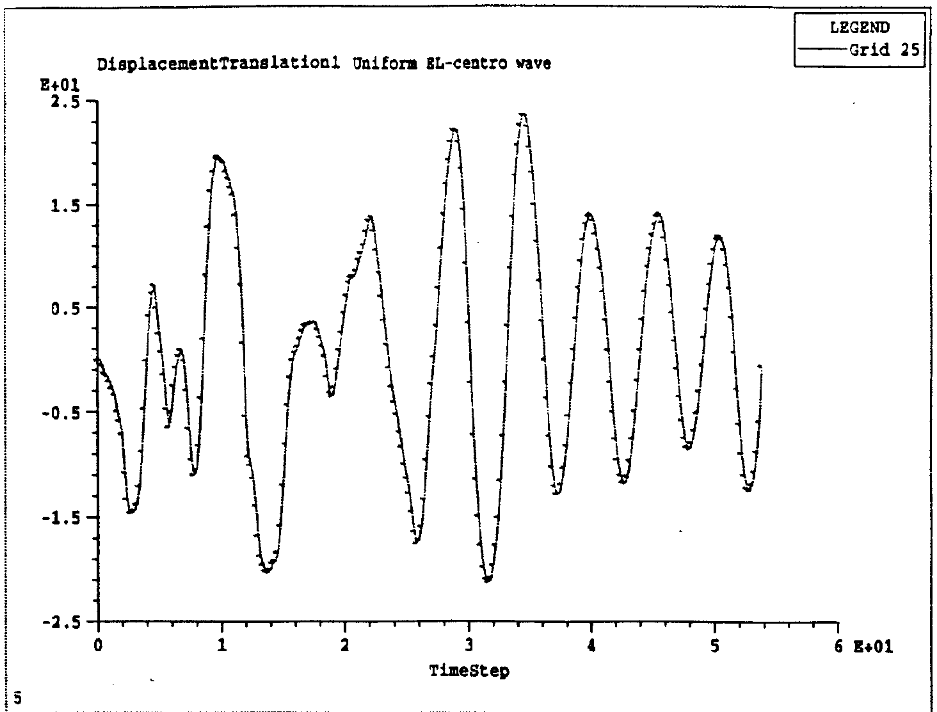

Fig. 2 Longitudinal displacement response of tower top under uniform El-centro wave

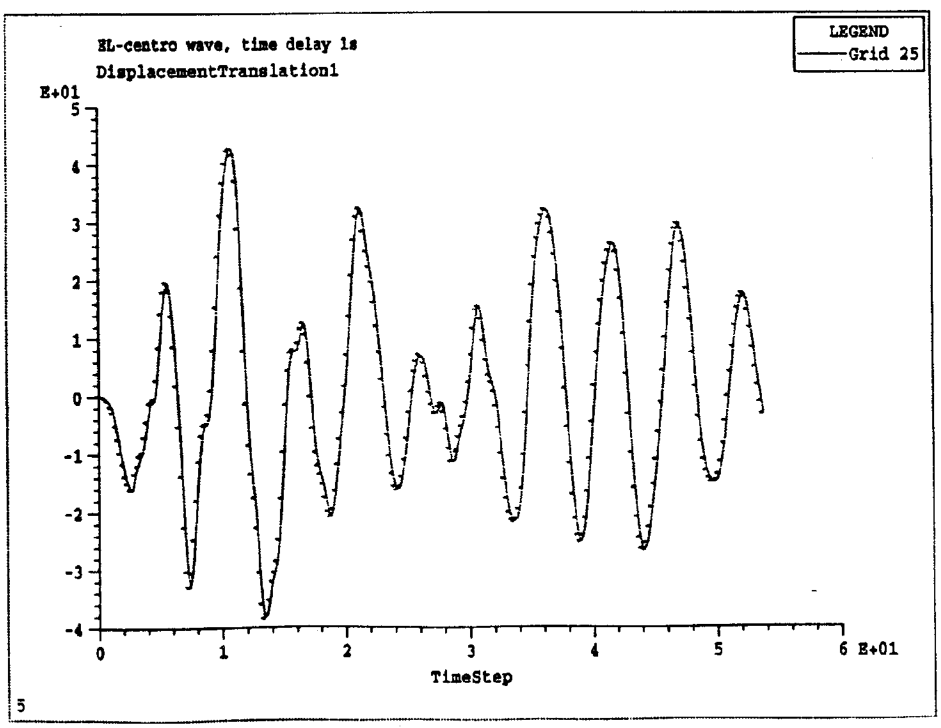

Fig. 3 Longitudinal displacement response of tower top under EL- centro wave with time delay 1 s between towers

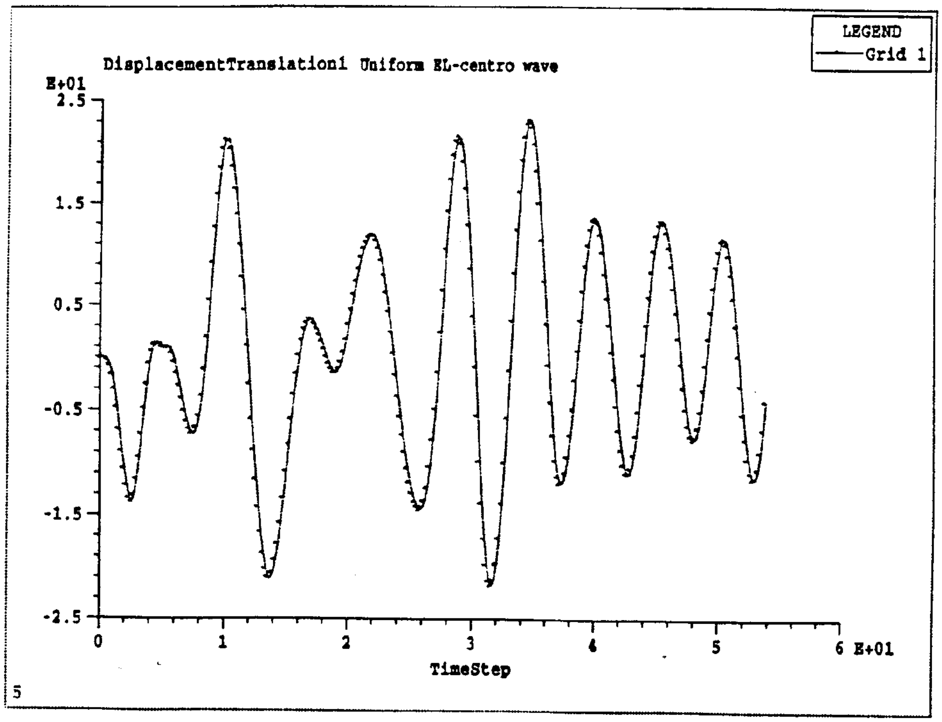

Fig. 4 Longitudinal displacement response of deck under uniform El-centro wave

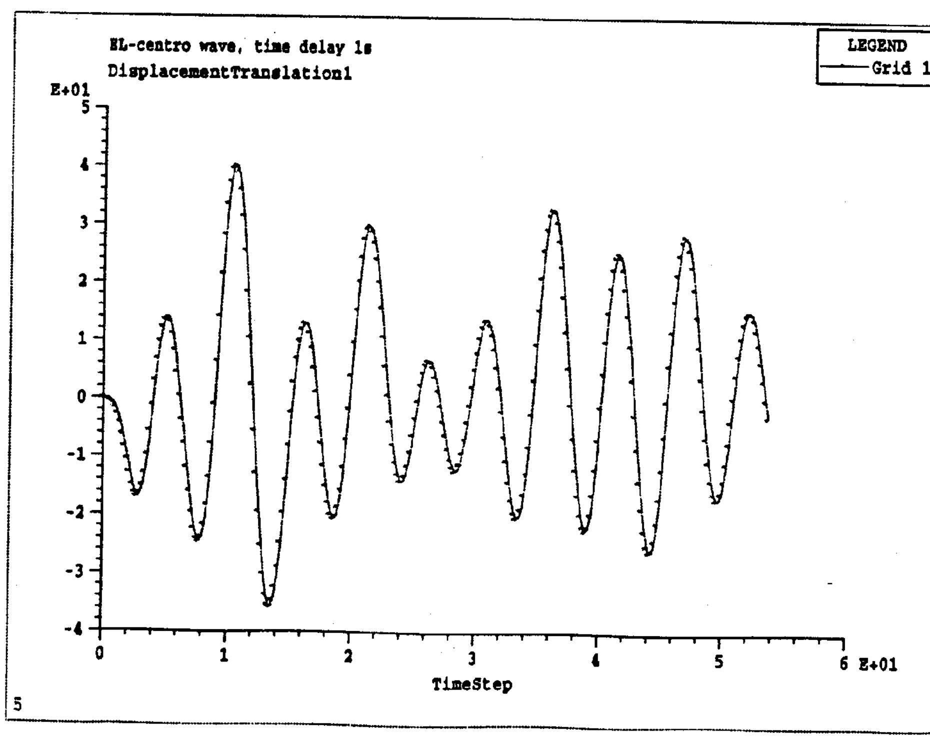

Fig. 5 Longitudinal displacement response of deck under El- centro wave with time delay 1 s between towers

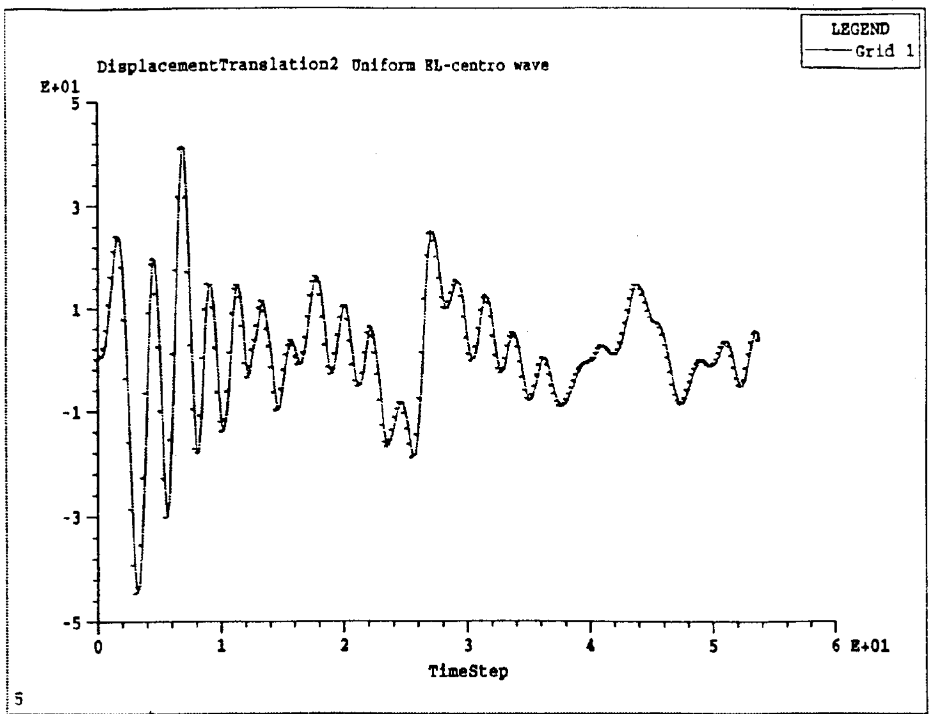

Fig. 6 Vertical displacement response of deck under uniform El-centro wave

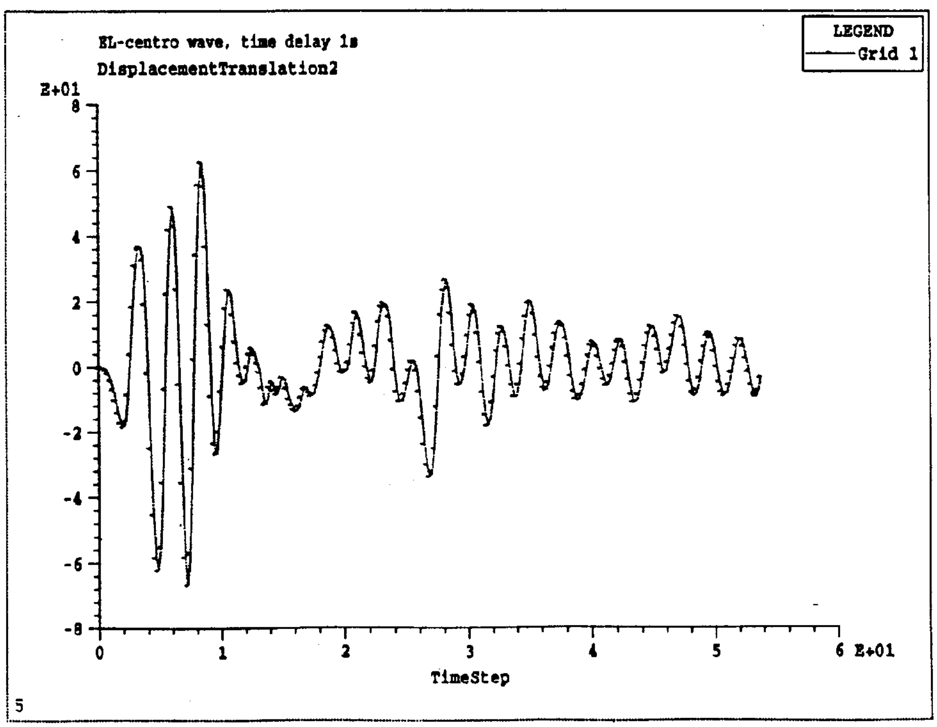

Fig. 7 Vertical displacement response of deck under El- centro wave with time delay 1 s between towers