Impact of pier length and connection type in static and dynamic response of RC bridge structure

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ABSTRACT

In this paper are presented analysis results of two bridges with similar geometry. The difference between them is in the length of piers.

3D (three-dimensional) mathematical model composed of RC piers (substructure) absolutely fixed at the base and RC deck (superstructure) are developed.

Both bridges are analyzed as Bridge Type 1 (with hinge connection between superstructure and substructure) and Bridge Type 2 (with fixed connection between superstructure and substructure). Superstructure is the same for both bridges.

Three analyses types are performed for both bridges:

- Static analysis including computation of displacements and element forces due to specified static loads.
- Analyses of structural dynamic characteristics including mode shapes and corresponding free-vibration periods.
- Dynamic response analyses under real earthquake ground excitation specified by corresponding input acceleration history.

Comparative analysis results of static and dynamic response for each Bridge Type, considering different connection between piers and superstructure are presented.

Keywords: *bridge, pier, static, dynamic, acceleration*

INTRODUCTION

The paper presented here is made as a result of work on analysis of two similar bridges. Both analyzed bridges have similar geometry. The difference between them is in the length of piers. Two bridges are analyzed here in detail.

Bridge A, has length of the longest pier H = 32.98 m, and the length of the other piers according to Fig. 1 Bridge B, has length of the longest pier H = 46.35 m, and the length of the other piers according to Fig. 1 as well.

Both bridges are analyzed as Bridge Type 1 (with hinge connection between superstructure and substructure) and Bridge Type 2 (with fixed connection between superstructure and substructure). Superstructure is the same for both bridges.

In **Problem 1 (Static and Seismic Analysis of Bridge Structure Type 1)** the results obtained by static and dynamic analysis for Bridge Type 1, both for Bridge A (regarded as 1/A) and Bridge B (regarded as 1/B) are presented.

For static analysis, the results obtained allowed for dead loads only for both Bridge A and Bridge B are presented.

In **Problem 2 (Static and Seismic Analysis of Bridge Structure Type 2)** the results obtained by dynamic analysis for Bridge Type 2, both for Bridge A (regarded as 2/A)and Bridge B (regarded as 2/B) are presented.

1. Static and Seismic Analysis of Bridge Structure Type 1

1.1 Geometrical characteristics of adopted static and dynamic system

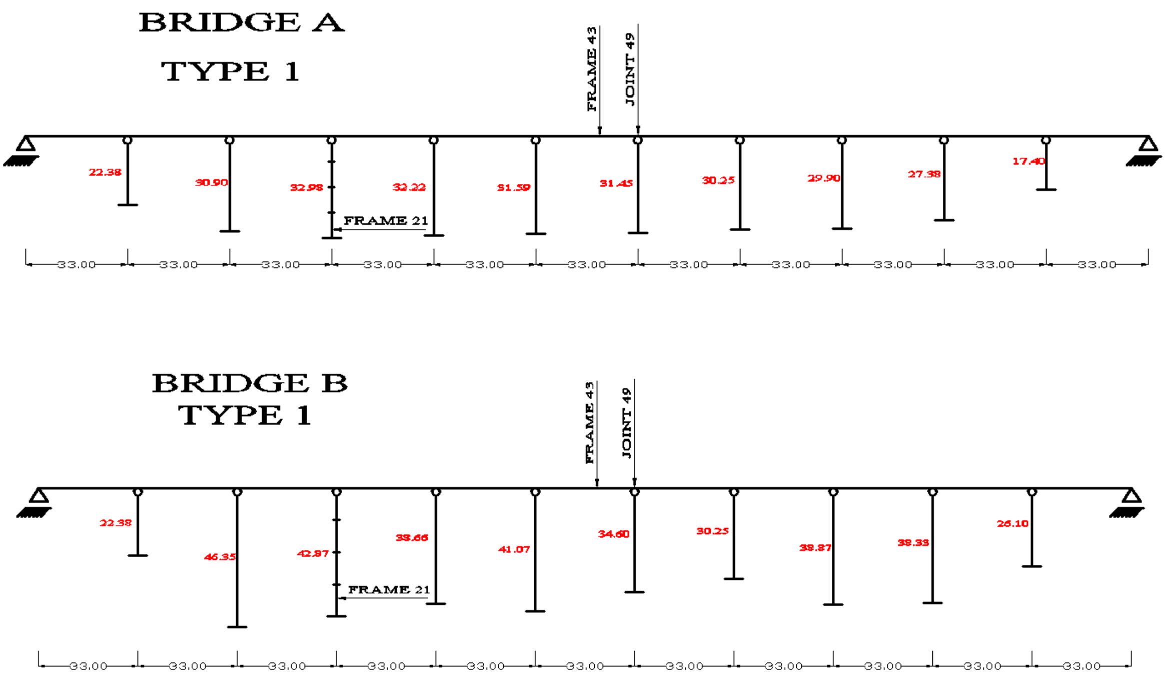


Figure 1. Bridge type 1/A and 1/B

1.2 Geometrical characteristics of cross section of bridge deck and piers

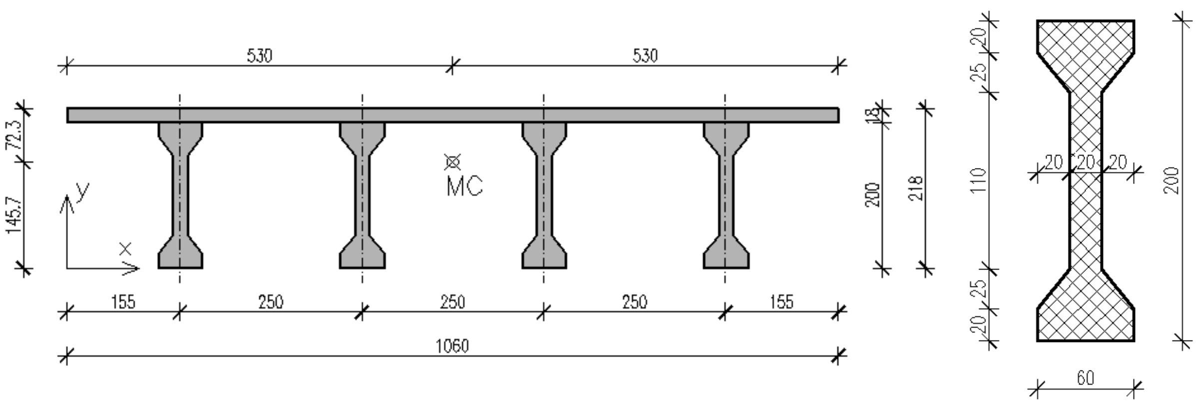


Figure 2. Cross section of bridge superstructure and beam element

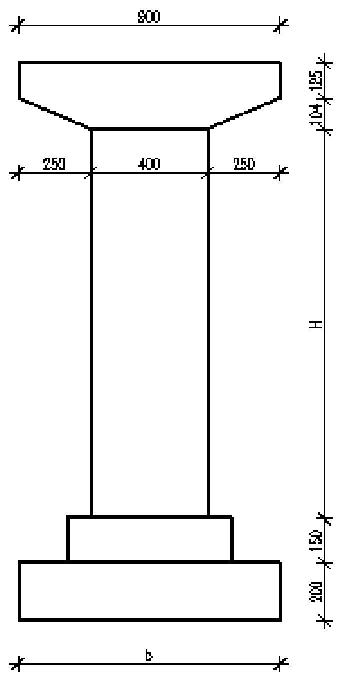
Table 1. Length of piers

Piers	H_i [m]	
	Bridge A	**Bridge B**
1	22.38	22.38
2	30.9	46.35
3	32.98	42.87
4	32.22	38.66
5	31.59	41.07
6	31.45	34.6
7	30.25	30.25
8	29.9	38.87
9	27.38	38.33
10	17.4	26.1

Table 2. Geometrical and physical characteristics of superstructure cross section

Area:	A [m^2]	4.548
Centroid:	X [m]	5.3
	Y [m]	1.4573
Moment of inertia:	I_X [m^4]	2.5817
	I_Y [m^4]	38.5353
Modulus of elasticity:	E [kN/m^2]	$3.15 \cdot 10^7$
Weight density:	W [kN/m^3]	24

Table 3. Geometrical and physical characteristics of substructure cross section



Area:	A [m^2]	4.0000
Centroid:	X [m]	2.0000
	Y [m]	0.5000
Moment of inertia:	I_X [m^4]	0.3333
	I_Y [m^4]	5.3333
Modulus of elasticity:	E [kN/m^2]	$3.15 \cdot 10^7$
Weight density:	W [kN/m^3]	24

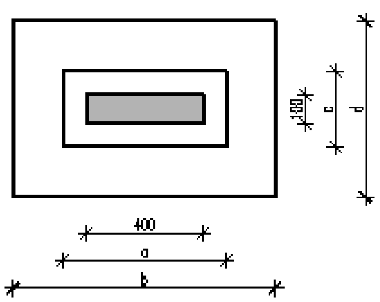


Figure 3. Geometrical characteristics of pier

1.3 Definition of loads

1.3.1 Dead loads analysis

- Self-weight of structure is computed automatically by computer program SAP 2000
- Additional distributed dead load is taken as: ....3.00 kN/m^2
- Additional dead load on beam elements: .... 3.00 · 10.60 = 31.80 kN/m

Masses resulting of self-weight of structural elements (both deck and piers) in computation of Eigen value problem and dynamic response of the system are calculated by SAP 2000.

Masses of additional dead loads considered as concentrated in nodal points, at each ¼ of span are:

$m_i = (8.25 \cdot 31.8) \ / \ 9.81 = 26.74 \ kNs^2/m$

1.3.2 Dynamic load analysis

Structure is subjected to EQ-1:Ulcinj-Albatros,Montenegro with PGA = 0.45 g.

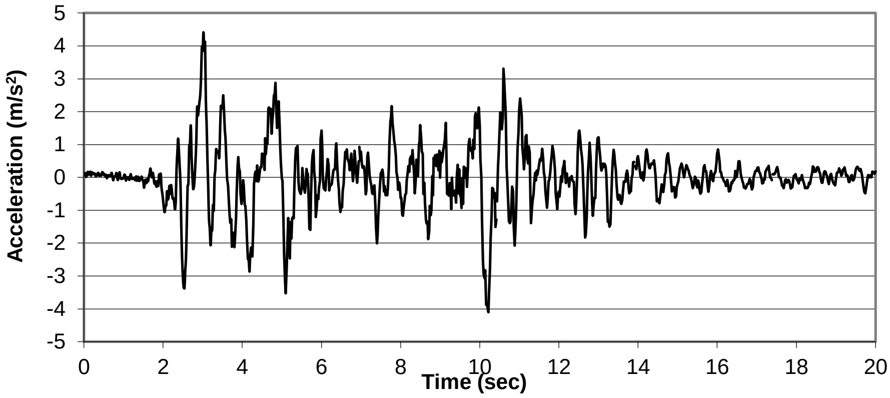


Figure 4. Acceleration Time History of Ulcinj-Albatros Earthquake

Earthquake record used in analysis was with PGA = 0.225g. In order to have input earthquake with PGA = 0.45g, that record was multiplied with intensity scaling factor $F_{sc} = 2 \cdot 10^{-3}$. Duration of earthquake record was 20 sec, with time step $\Delta t = 0.02$ sec.

This earthquake excitation was used for the analysis both in X and Y direction.

Modal damping for all modes was taken as $\xi = 0.05$. Output was set to 200 steps with time step $\Delta t = 0.1$ sec.

Linear dynamic analysis in both direction was performed.

1.4 Scheme of Characteristic Frames and Joints Analyzed (1/A)

1.4.1 Static analysis (dead load)

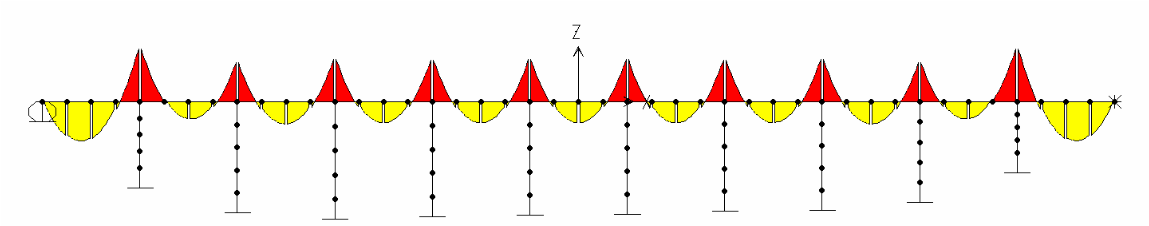


Figure 5. Bending Moments [kNm]

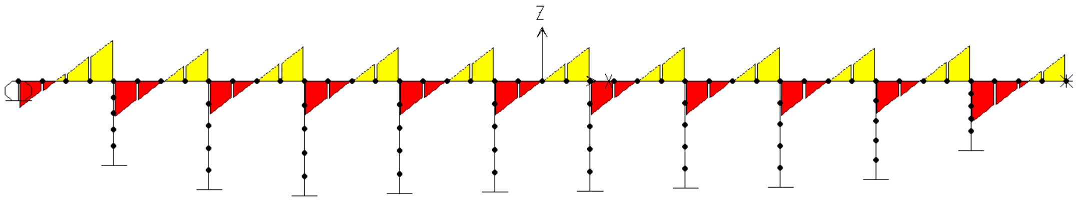


Figure 6. Shear Forces [kN]

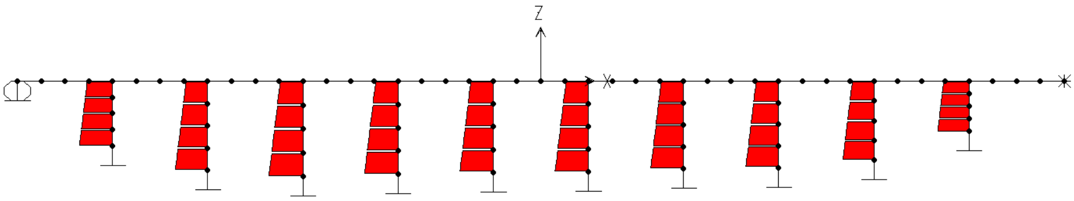


Figure 7. Axial Forces [kN]

Dynamic properties of Bridge Type 1 (1/A); (1/B)

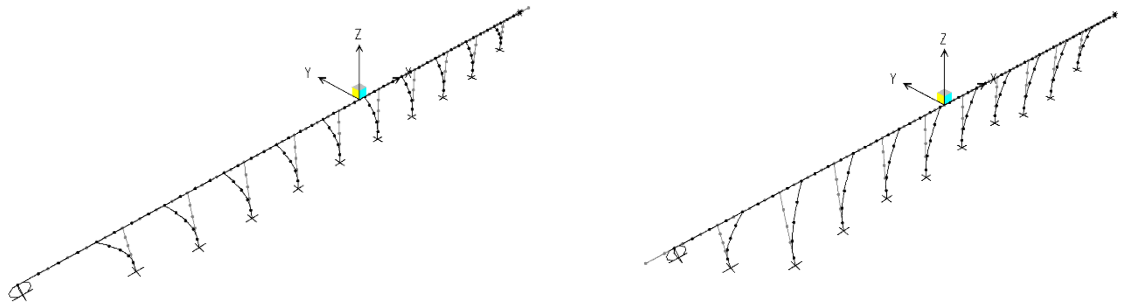


Figure 8. Mode shape 1

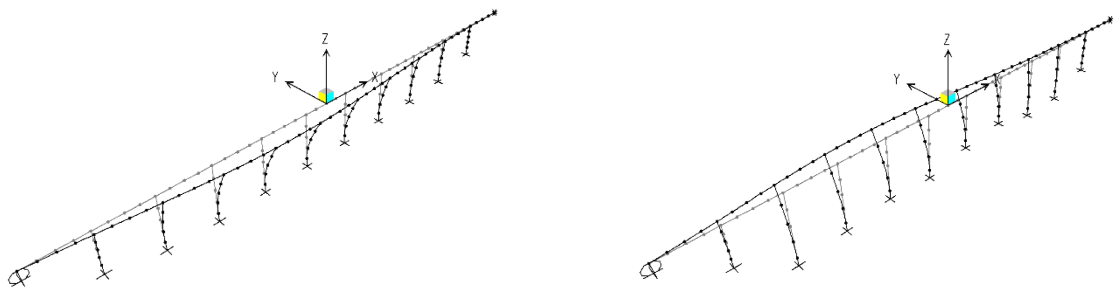


Figure 9. Mode shape 2

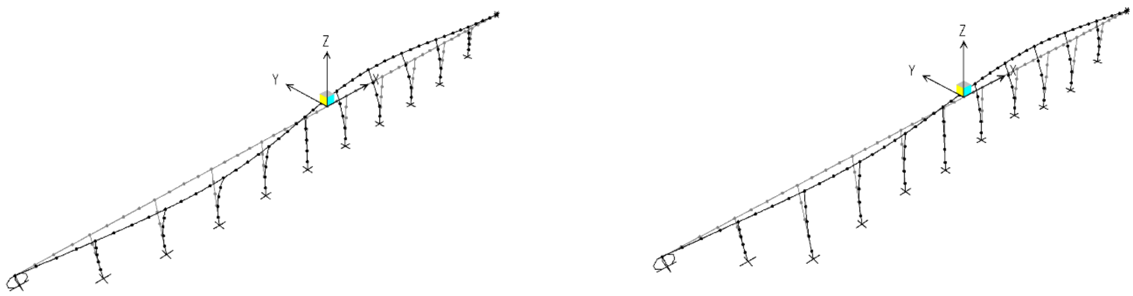


Figure 10. Mode shape 3

Table 4. Bending, Shear and axial forces

Bridge Type 1	Max Bending moment, Mmax	Min Bending moment Mmin	Max Shear Force, Tmax	Min Axial Force
	[kN m]	[kN m]	[kN]	[kN]
Bridge 1/A	8949	6633	1556	-3852
Bridge 1/B	9004	6630	1562	-4333

Table 5. Natural Periods of Vibrations

Mode shape	Natural Period of Vibration T [sec]	
	Bridge 1/A	Bridge 1/B
1	2.6802	3.7247
2	0.834	1.0933
3	0.6907	0.8796

1.5 Comparative Dynamic analysis for Bridge 1/A and Bridge 1/B,

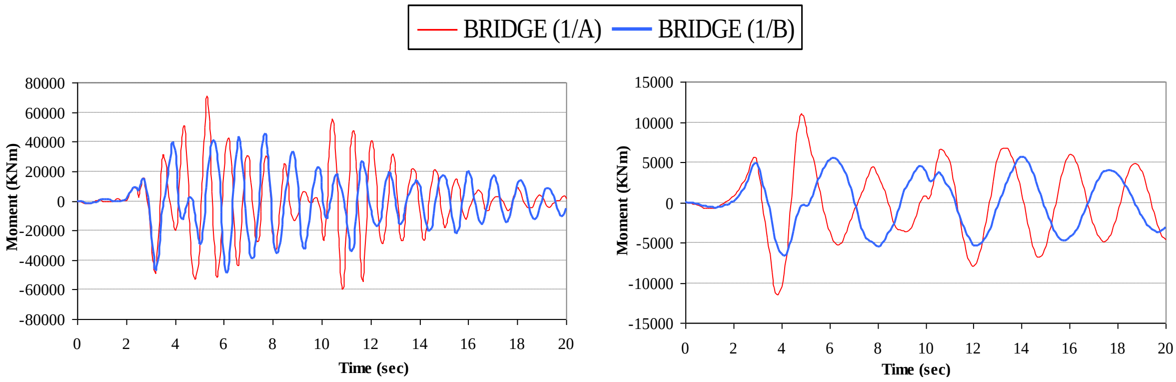


Figure 11. Time history $M_{x,21}$, $M_{y,21}$

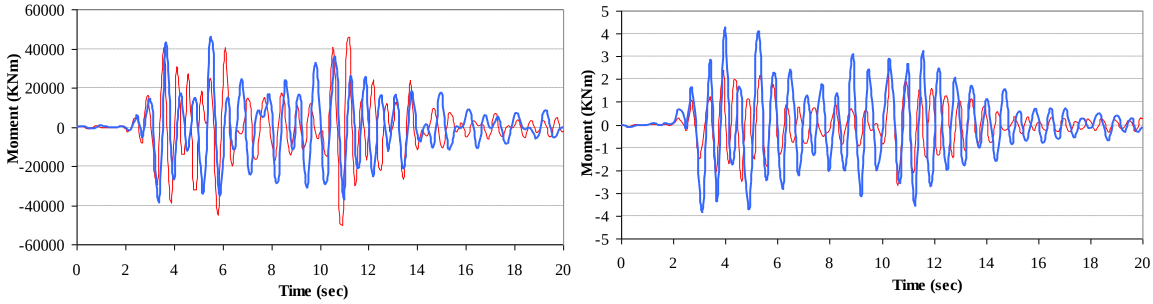


Figure 12. Time history $M_{x,43}$, $M_{y,43}$

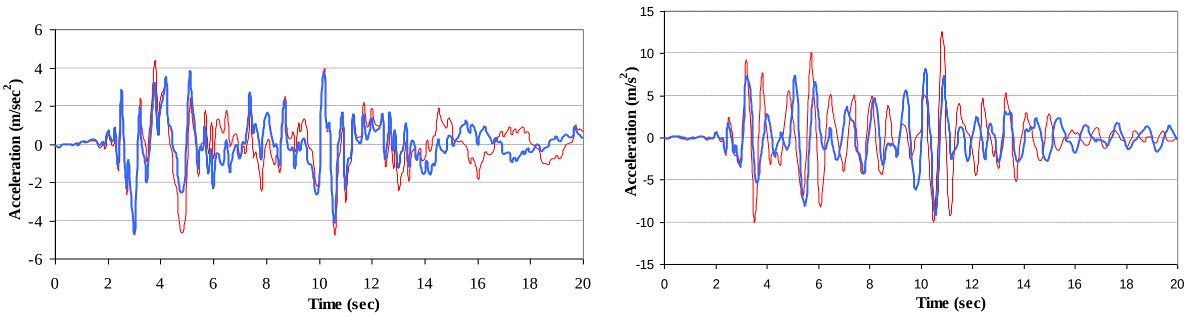


Figure 13. Time history $Acc_{x,J49}$, $Acc_{y,J49}$

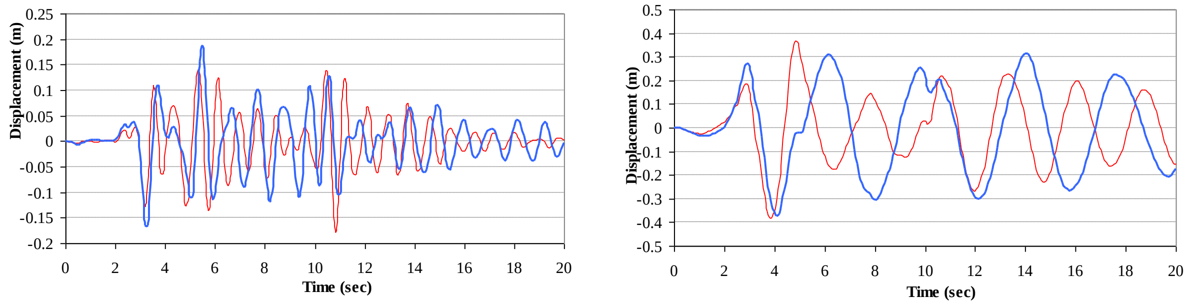


Figure 14. Time history $Displ_{x,J49}$; $Displ_{y,J49}$

Table 6. Maximum Absolute Amplitudes of Selected Responses

Bridge Type 1		ux	vx	ax	uv	vv	av	BSx	BSy
		[m]	[m/s]	[m/s²]	[m]	[m/s]	[m/s²]	[kN]	[kN]
Bridge 1/A	max. Amp	0.3828	1.2345	4.6281	0.1793	1.4000	12.5532	7030	22810
	Time [sec]	3.8	4.4	4.8	10.8	11.0	10.8	3.8	5.3

Bridge 1/B	max. Amp	0.3725	0.9178	4.7626	0.1880	1.1173	9.0359	3885	15800
	Time [sec]	4.1	3.6	3.0	5.5	5.3	10.6	4.1	3.2

2. Static and Seismic Analysis of Bridge Structure Type 2

2.1 Geometrical characteristics of adopted static and dynamic system

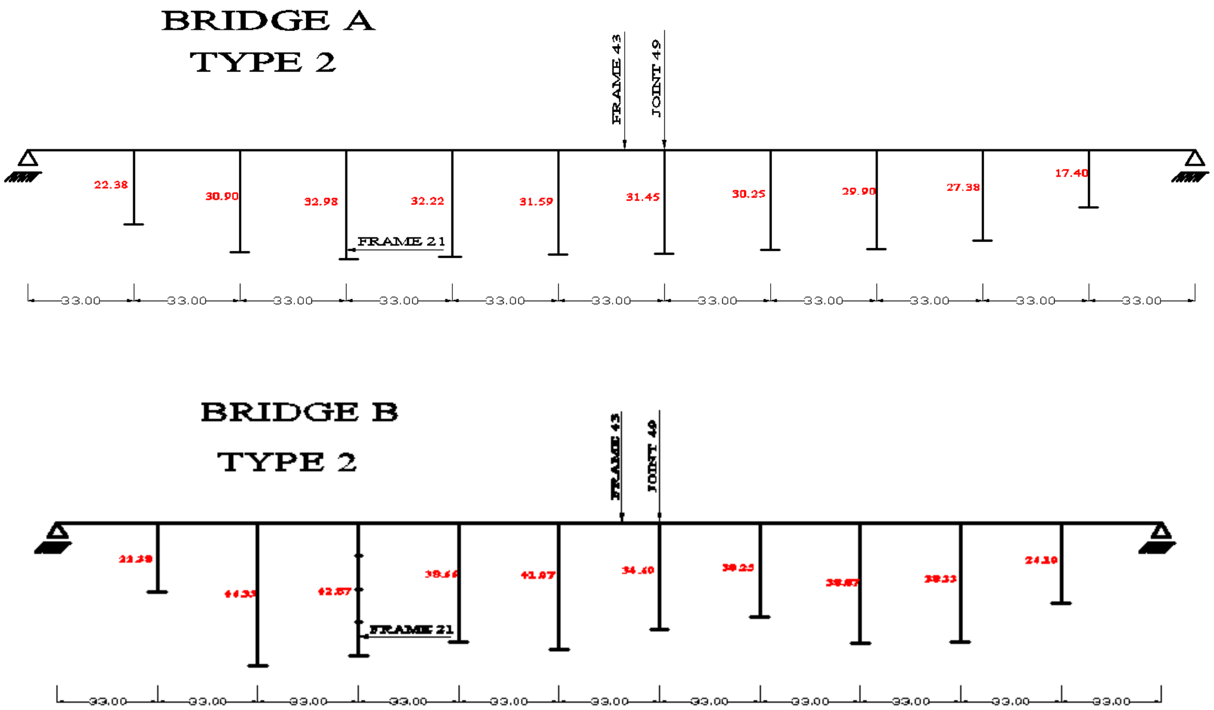


Figure 15. Bridge type 2/A and 2/B

Dynamic properties of Bridge Type 2 (2/A); (2/B)

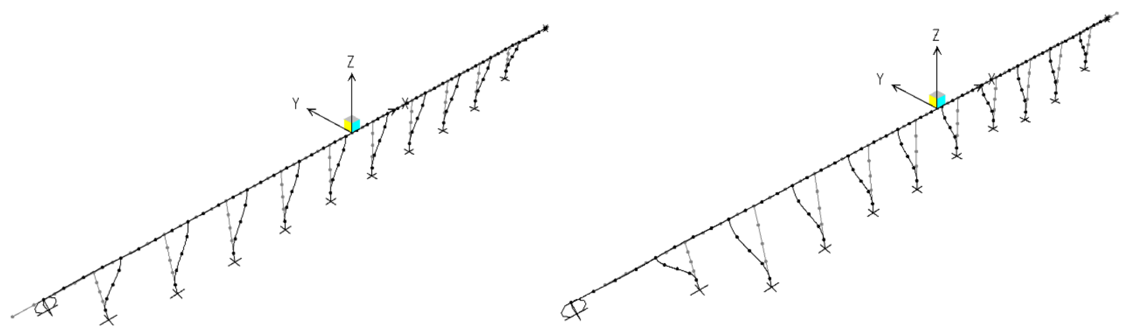


Figure 16. Mode Shape 1, Bridge Type 2 (2/A and 2/B)

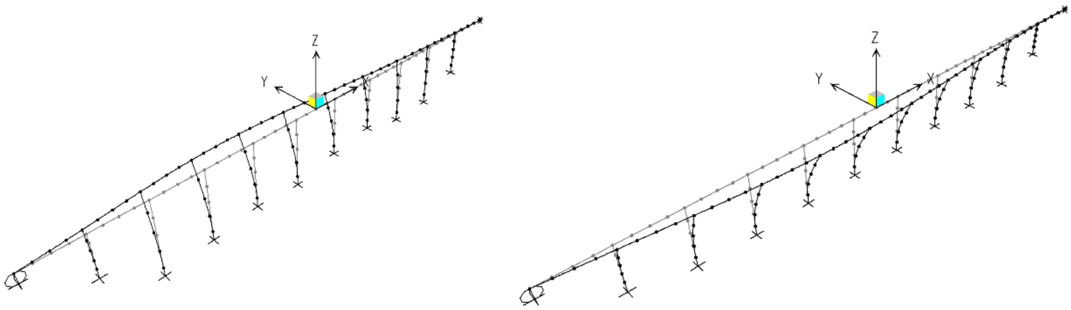


Figure 17. Mode Shape 2, Bridge Type 2

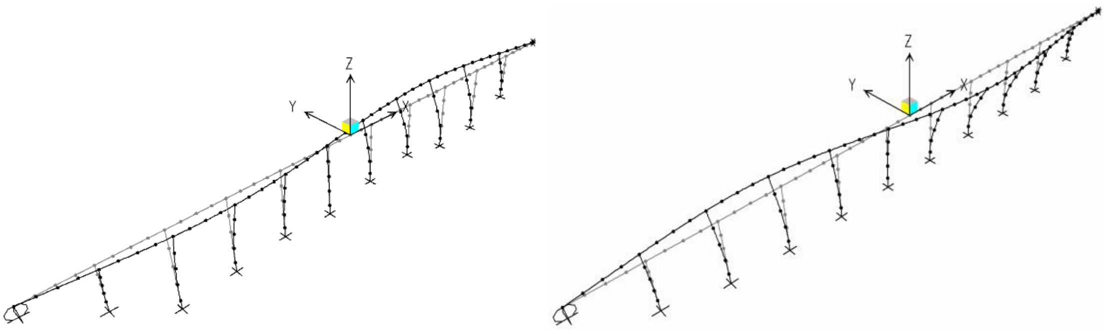


Figure 18. Mode Shape 3, Bridge Type 2 (2/A& 2/B)

Table 7. Natural Periods of Vibrations

Mode shape	Natural Period of Vibration T [sec]	
	Bridge 2/A	Bridge 2/B
1	1.7508	1.9621
2	1.0068	1.0741
3	0.8121	0.8367

2.5 Comparative Dynamic analysis for Bridge 2/A and Bridge 2/B,

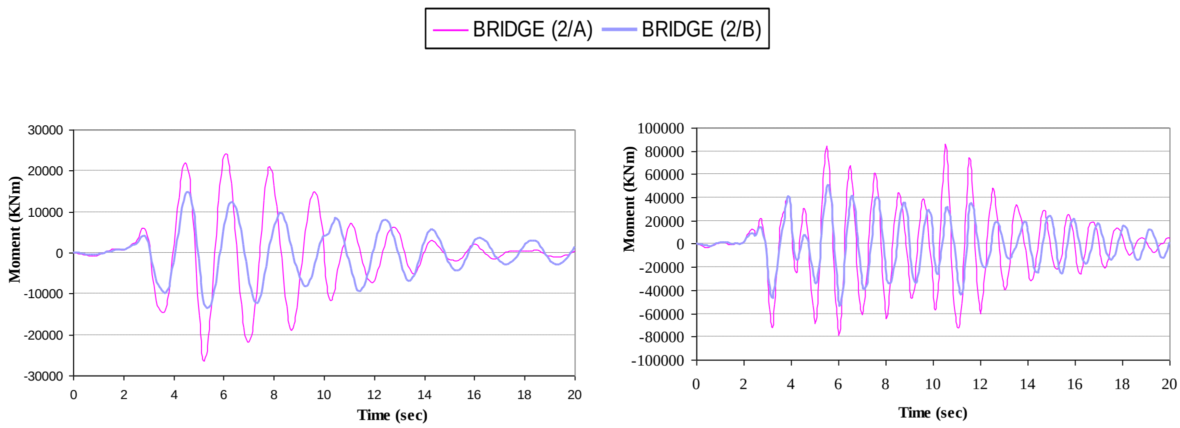


Figure 19. Time history $M_{x,21}$, $M_{y,21}$

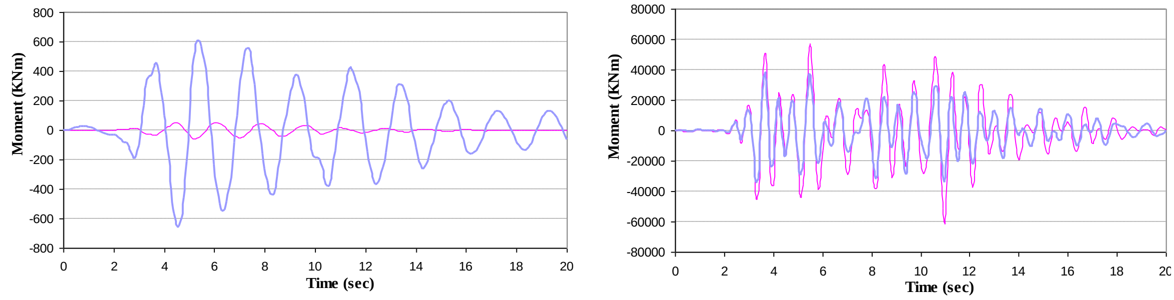


Figure 20. Time history $M_{x,43}$, $M_{y,43}$

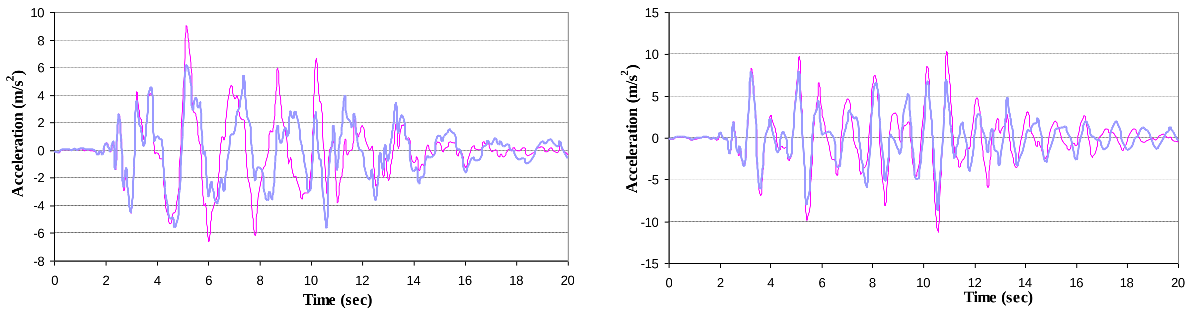


Figure 21. Time history $Acc_{x,J49}$, $Acc_{y,J49}$

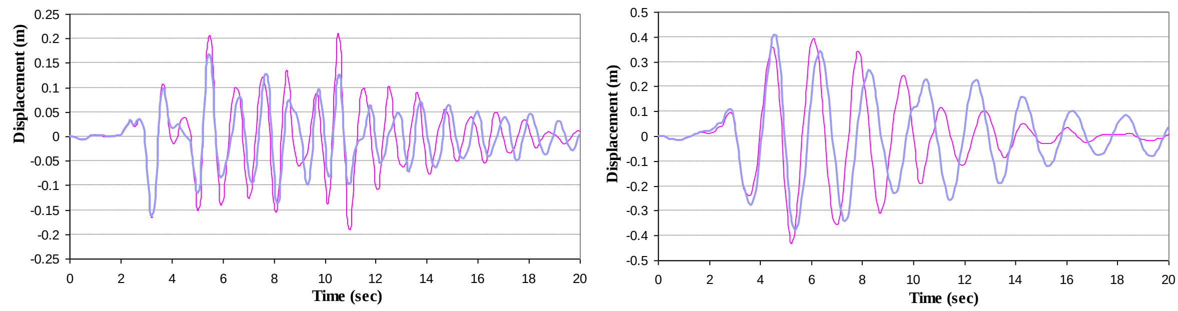


Figure 22. Time history $Displ_{x,J49}$; $Displ_{y,J49}$

Table 8. Maximum Absolute Amplitudes of Selected Responses

Bridge Type 2		u_x	v_x	a_x	u_v	v_v	a_v	BS_x	BS_y
		[m]	[m/s]	[m/s²]	[m]	[m/s]	[m/s²]	[kN]	[kN]
Bridge 2/A	max. Amp	0.4314	1.7039	8.9497	0.2109	1.4934	11.1581	30360	26320
	Time [sec]	5.2	4.9	5.1	10.5	10.7	10.6	5.2	10.5
Bridge 2/B	max. Amp	0.409	1.7215	6.173	0.1672	1.0553	8.5568	15300	15650
	Time [sec]	4.6	5	5.1	5.5	5.3	10.6	4.6	3.2

CONCLUSIONS

Analysis results of static and dynamic response above presented shows that:

3. 1 In bridges with hinge connection between superstructure and substructure

- Bending moments in piers of Bridge A are higher than those on Bridge B because of lower pier stiffness values of the latest. Maximum bending moments ratio of piers is 1.5 ÷ 2.0 approximately in both directions (Figure 11, M_{x21}, M_{y21}). So, influence of higher modes is greater on long piers of Bridge B, then on respective piers of Bridge A.
- Bending moments M_x in bridge superstructure are higher in Bridge B because of influence of the more flexible piers compared to that Bridge A, while their amplitudes are negligible. Bending moments M_y are similar for both bridges, (Figure 12, M_{x43}, M_{y43}).
- Acceleration amplification is greater at Y direction than at X direction and it is greater for Bridge A than for Bridge B,(Figure 13, $Acc_{x,J49}$, $Acc_{y,J49}$) which is consequence of frequency content of selected earthquake and appropriate fundamental modes.
- Base-shear amplification follow the same pattern as acceleration amplification. Base-shear coefficient has values between 0.16 to 0.54 and 0.08 to 0.33 for Bridge A and B respectively (Table 6).

3. 2 In bridges with with fixed connection between superstructure and substructure:

- Bending moments in piers of Bridge A are higher than those on Bridge B because of lower pier stiffness values of the latest. Maximum bending moments ratio of piers is 2.0 approximately in both directions (Figure 19, M_{x21}; M_{y21}).
- Bending moments for X direction in superstructure above bridge pier have significant values, which is consequence of the type of fixed connection between substructure and superstructure, (Figure 20. $M_{x,43}$). The moment values for Bridge A near the pier support are higher, while on midpoint of inner span are much lower compared to Bridge B. Bending moments M_y are similar for both bridges with slightly higher values of Bridge A (Figure 20. $M_{y,43}$).
- Acceleration amplification is greater at Y direction than at X direction and it is greater for Bridge A than for Bridge B,(Figure 21, $Acc_{x,J49}$, $Acc_{y,J49}$), which is consequence of frequency content of selected earthquake and appropriate fundamental modes.
- Base-shear amplification follow the same pattern as acceleration amplification. Base-shear coefficient has values between 0.62 to 0.72 and 0.30 to 0.33 for Bridge A and B respectively(Table 8).

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