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Strength and performance evaluation of Nepalese RC bridge pier using non-linear dynamic response analysis through mathematical modelling

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Abstract

During the 1989 Loma Pita Earthquake (M 7.1) in California, widespread damage was reported to the region's highway and bridges. Five different condition of Bridge pier have been considered with investigation of all the data base of Department of Road (DOR). Available bore-hole soil database of the bridge have been utilized. The analysis showed mat me KL tnagc Pier is safer in the event of earthquakes for simulating the ground conditions encircling the pier. The performance of the RC Bridge Pier was accessed in strong ground motion records. In this study it was intended to access the seismic performance of RC bridge piers under Gazali strong motion. It was observed in the field observation that most of the bridges in Kathmandu Valley were having lowered bed due to scouring. The effect of strong vertical ground motion was investigated for possible reduction in flexural and shear strength of the pier. For this purpose, fifteen models have been developed. These fifteen models are grouped into three sets. First set consists of the five models having only horizontal direction of earthquake is applied. Second set consists of five models with horizontal & Vertical direction of earthquake is applied and third Set consist of the five models with Scouring is considered. These studies have revealed that have got profound effect on the performance of the RC structures. The lateral extent of soil mass for each of the five different bridges were fixed based on trial computations until the percentage difference in consecutive response quantities were found within the limit of 0.4%. The lateral extent for the AO is fixed as 400m, AW is fixed as 500m, AP is fixed as 400m, IP is fixed z 500m and BPIs fixed as 400m. The light damage, considerable damage and also failure damage of the Bridge pier at different bridges for different cases (AO, AW, AP and BP). The introduction of strong vertical ground motion increase the vertical displacement by 48% all bridges. It means horizontal ground acceleration (0.71g) and vertical ground acceleration (1.37g) both applied horizontal displacement increases as well as vertical displacement increases. The Nepalese RC Bridge Pier (In 1990-2015) is over safe. The Nepalese RC Bridge Pier (After 2000 and Before 1990) is designed under safe.

Keywords: Vulnerability, non linear dynamic, RC modelling, performance evaluation, mathematical modelling.

Introduction

The process of convergence of the t plates is known the tectonic activity. Large amount of energy is accumulated over the region and its eruption in the form of earthquake is today o tomorrow in geological terms. It is this process which makes the Himalayan and the surrounding region one of the seismically active regions on the earth All structures that are to be constructed in Nepal must be designed taking into the effect of earthquakes[1]. In light of the worldwide damages that occurred in different kinds of structures, safety of these structures has become a prime concern. Detailed investigations of the seismic performance of the structures that were already constructed in the past or that arc currently under construction and the structures that will be constructed in future have to be made with different considerations in seismic design[2]. Nepal is a mountainous country and there is lots of variation in geology. Nationwide transportation network require a large number of bridges to connect the road on side of the river. Development of transportation infrastructure is the top priority of the Government of Nepal (GoN) and hundreds/thousands of bridges are on its way of design/consecution phase. In Nepal bcfore1980 there is no any specific code provisions or government regulations to design the structure for the earthquake effect. At that time there is lot of variation in design being followed. For identical bridge structure different designers have drastically different outputs: there are no rules for the earthquake design. Seismic performance evaluation and understanding is highly desirable for the DOR for these bridges. In Nepal there is large number of examples of failure of bridges quite earlier than expected design life time[3].

There are many bridges which showed earlier collapse due to scoring and lower of bed level[4].The bed lowering is especially a local problem of bridges on the rivers of Kathmandu Valley due to unauthorised excavation of sand for urban construction.

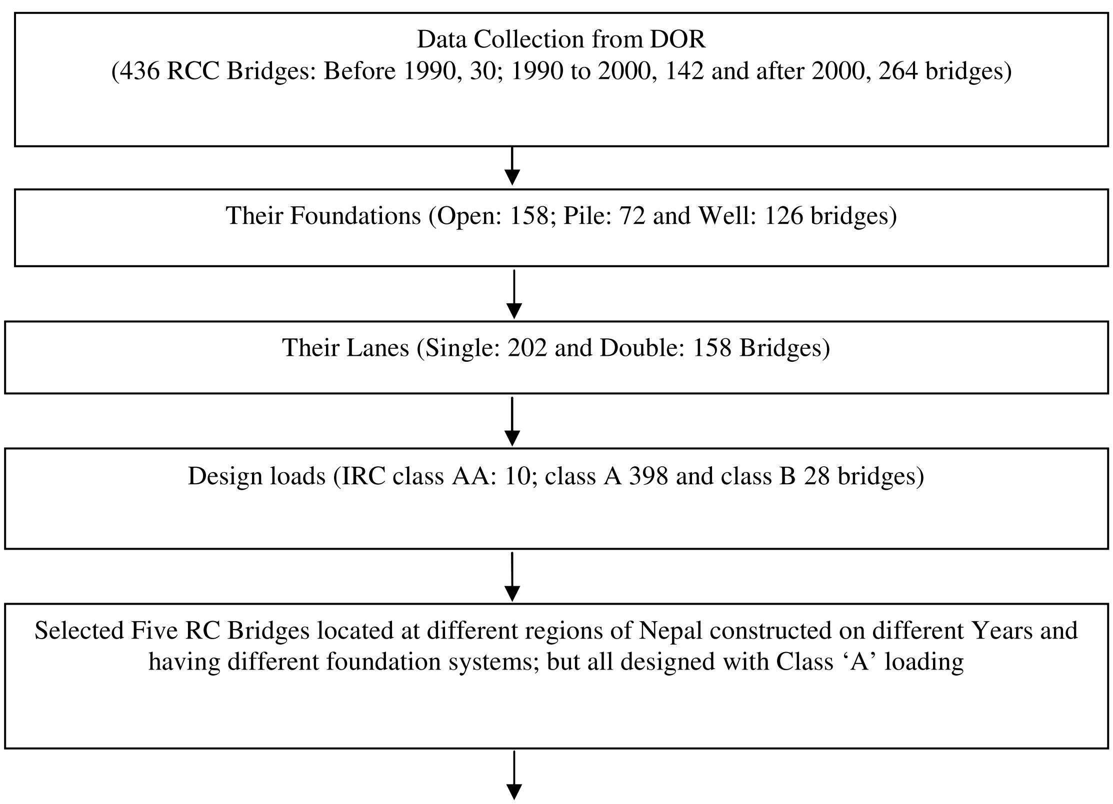
Problem and Issues: In Nepal before l980 there are no any specific code provisions or government regulations to design the structure for the earthquake effect. At that time there is lot of variation in design being followed. For identical bridge structure different designers have drastically different outputs: there are no rules for the earthquake design. Seismic performance evaluation and understanding is highly desirable for the DOR for these bridges. In Nepal there is large number of examples of failure of bridges quite earlier than expected design life time. There are many bridges which showed earlier collapse due to scoring and lower of bed level. The bed lowering is especially a local problem of bridges on the rivers of Kathrnandu Valley due to unauthorized excavation of sand for urban construction[5].

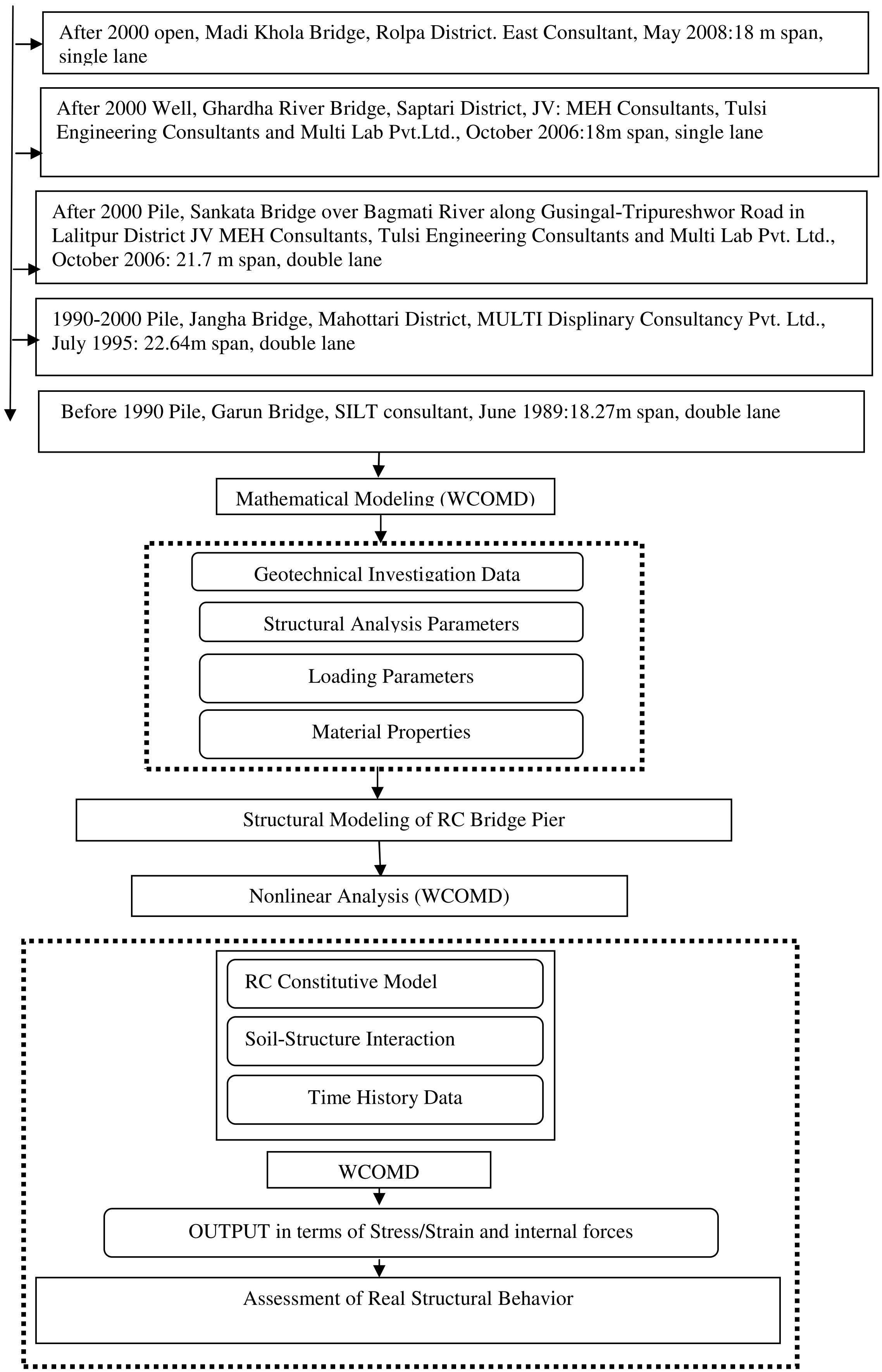
Wide Variation in reinforcement exists for almost identical bridges. Variation in types of foundation / soil characteristics adopted exists due to variation in geological / soil characteristics[6]. Many urban bridges have problem of Scouring and subsequent bed lowering with increased effective length/span of the bridge pier[7]. Nepal is prone to severe earthquake but, seismic designs are not entertained. Bridges are seismically vulnerable. Soil structure interaction and non-linear RC response under strong ground motion needs to be understood for Nepalese bridges for its seismic performance evaluation. So "what is the condition of bridges of Nepal?" needs to be answered with high level of confidence.

Materials and methods

The different country codes of bridge analysis and design, necessary loading data, geotechnical investigation reports, structural design report and the drawings will be collected from the Bridge Unit, department of road (DOR), Babarmahal, Kathmandu. Field observation of different bridges of Kathmandu Valley, to find out average representative bed lowering of bridges due to scouring problem. Select some typical bridges from different region of Nepal. Nonlinear finite element analysis using WCOMD software will be carried out to identify the real behaviour of the structure subjected to static and dynamic loading conditions (Okamura, H. and Maekawa, K. 1991)[8]. The comparison of the results of the linear elastic analysis based design and that of nonlinear seismic performance analysis will then be made to identify the deficiencies and gap between the real structural behaviour and the presently employed methodologies of analysis and design. The Flow chart of Non-linear dynamic.

Geological Profile at Nepalese RC Bridge Pier: The RC Bridge Pier is located different region of Nepal. The deposits consist of alternating beds of sand, sand & clay and clay soil[9]. The bedrock is not found at least up to the depth of 40 meters. It has been proposed to run the Open, Pile and Well Foundation through the sand, sand & clay and clay beds of deposits with about 20 meters deep cutting. The soil profile at the Bridge Pier is broadly divided into two layers[10].




After 2000 open, Madi Khola Bridge, Rolpa District. East Consultant, May 2008:18 m span, single lane
After 2000 Well, Ghardha River Bridge, Saptari District, JV: MEH Consultants, Tulsi Engineering Consultants and Multi Lab Pvt.Ltd., October 2006:18m span, single lane
After 2000 Pile, Sankata Bridge over Bagmati River along Gusingal-Tripureshwor Road in Lalitpur District JV MEH Consultants, Tulsi Engineering Consultants and Multi Lab Pvt. Ltd., October 2006: 21.7 m span, double lane
1990-2000 Pile, Jangha Bridge, Mahottari District, MULTI Displinary Consultancy Pvt. Ltd., July 1995: 22.64m span, double lane
Before 1990 Pile, Garun Bridge, SILT consultant, June 1989:18.27m span, double lane
Mathematical Modeling (WCOMD)
Geotechnical Investigation Data
Structural Analysis Parameters
Loading Parameters
Material Properties
Structural Modeling of RC Bridge Pier
Nonlinear Analysis (WCOMD)
RC Constitutive Model
Soil-Structure Interaction
Time History Data
WCOMD
OUTPUT in terms of Stress/Strain and internal forces
Assessment of Real Structural Behavior

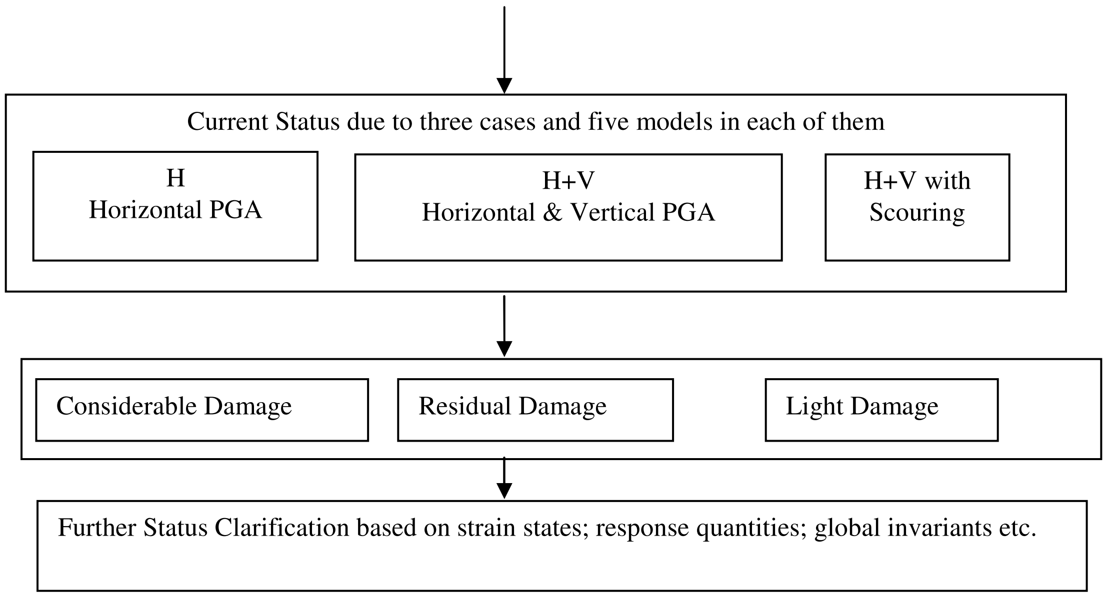


Figure-1: The flow diagram for the work.

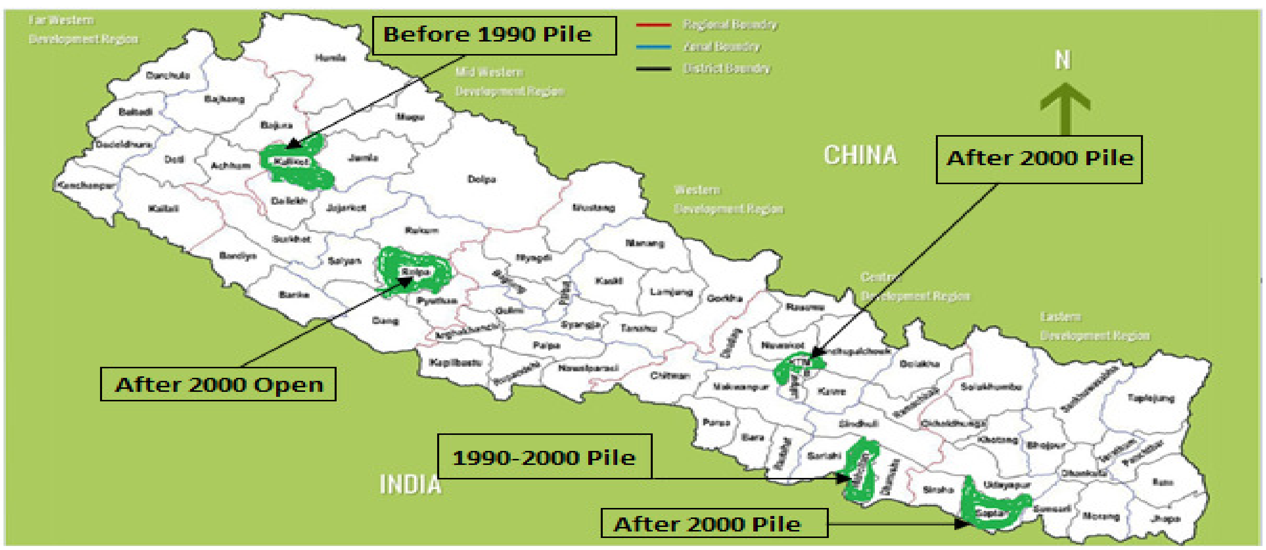


Figure-2: Selected RC Bridge Pier for Computation[11].

Results and discussion

All together fifteen analyses were conducted; among them three Nepalese RC Bridge pier are after 2000 open, three Nepalese RC Bridge pier are after 2000 well, three Nepalese RC Bridge pier are after 2000 pile, three Nepalese RC Bridge Pier are intermediate 1990-2000 pile and three Nepalese RC Bridge Pier are before 1990 pile. The results of these analyses are presented in this section. The performance of the Nepalese RC Bridge Pier is evaluated in terms of mean inelastic strain, the damage criteria and the deformation of the structure. For the evaluation of the results they have been grouped into three categories[12]. To evaluate the performance of the Nepalese RC Bridge Pier, three cases of five Bridges model each of them are H, H+ V and H+V with Scouring were considered. The performance is expressed in terms of mean inelastic strain level, damage level and variation of stress and strain in time domain[13,14].

Damage Level: The five bridges (After 2000 open, After 2000 Well, After 2000 Pile, Intermediate 1990-2000 Pile and Before 1990 Pile) of different three cases (H, H+V, H+V with Scouring) damage location is shown in figure and also tabular form in table.

From Figure-3 it is clear that after scouring (After 2000 Pile), the bridge pier light damage, considerable damage and failure damage occurred and also pile foundation display light damage. It means scouring is effect the whole structure[15].

Deformation, Crack Pattern and Yield Locations: Figure-6 shows the maximum deformation profile of the base case model. In the Figure-6 we can clearly see the separation between the soil and the structure at various interface locations along the periphery of the structure. Figure-6 shows the crack[16].

Structural Result: This investigates shows that in time domain, an element, which experienced light damage due to stress and strain, has been chosen[17].

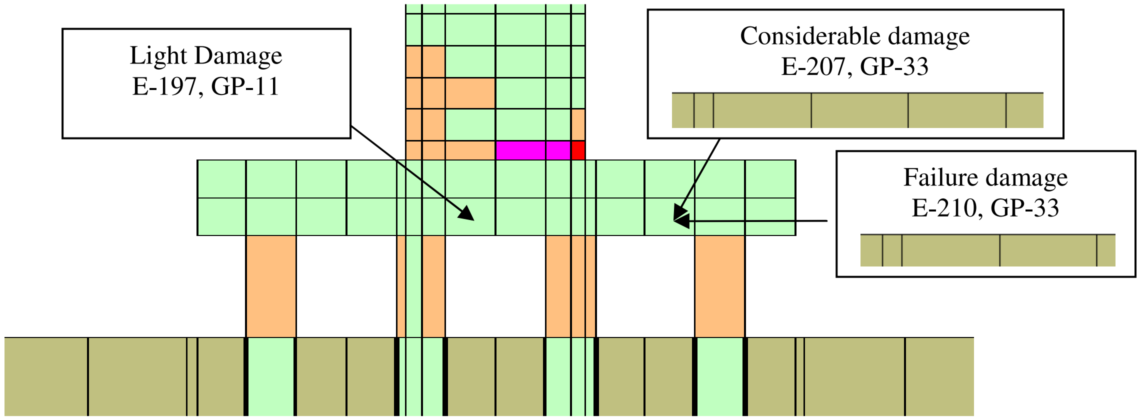


Figure-3: Damage Location in the RC Bridge Pier (After 2000 Pile, H+V with Scouring Cases).

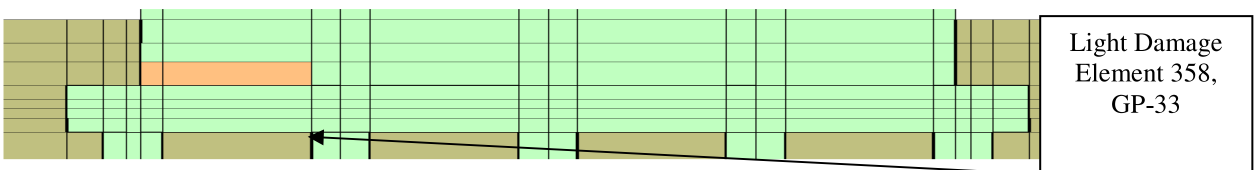


Figure-4: Damage Location in the RC Bridge Pier (Before 1990 Pile, H+V Cases).

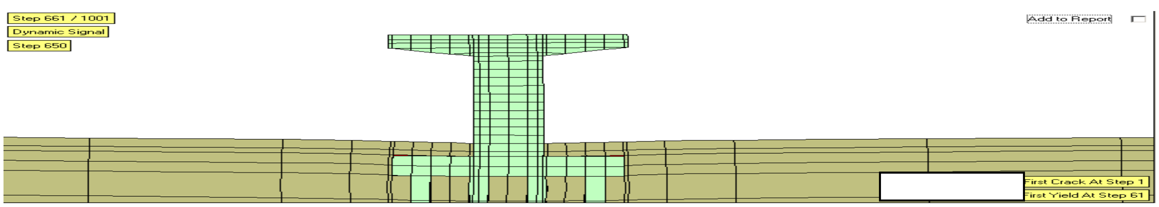


Figure-5: Deformation in the structure (After 2000 Pile).

Table-1: First Yield Result.

Description	Types of earthquake	Element / GP	Strain X	Strain Y
After 2000 open	Scouring H+V	302/23	5.07E-04	-1.97E-03
After 2000 Pile	H	309/31	-1.86E-04	2.55E-05
	H+V	370/31	-1.75E-04	2.32E-05
	Scouring H+V	191/31	-1.74E-04	2.34E-05
After 2000Well	H	449/23	2.27E-04	-8.70E-06
	H+V	449/23	2.27E-04	-8.70E-06
	Scouring H+V	397/23	2.61E-04	-5.49E-06
Before 1990	H	378/23	5.13E-06	-1.77E-04
	H+V	378/23	5.13E-06	-1.77E-04
	Scouring H+V	253/23	5.16E-06	-1.77E-04

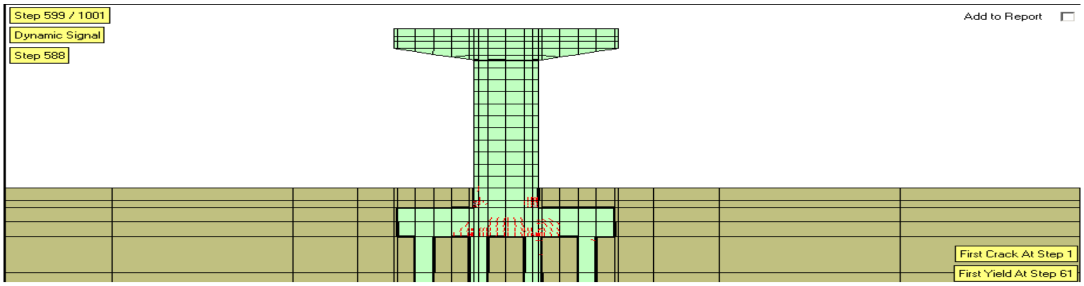


Figure-6: Crack in the structure (After 2000 Pile).

Table-2: First Crack Result.

Description	Types of earthquake	Element/Gauss Point	Mean normal strain		Mean shear strain		Crack angle (deg)
			E_x	E_y	G_{xx}	G_{xy}	
After 2000 open	H	175/23	2.49E-04	-1.88E-05	-5.93E-06	-5.93E-06	90
	H+V	175/23	2.49E-04	-1.89E-05	-6.06E-06	-6.06E-06	90
	Scouring H+V	175/23	2.61E-04	-1.79E-05	-1.23E-05	-1.23E-05	90
After 2000 Pile	H	234/23	6.81E-04	-2.80E-06	-7.02E-05	-7.02E-05	95
	H+V	234/23	5.77E-04	-3.54E-06	-4.91E-05	-4.91E-05	95
	Scouring H+V	187/33	9.69E-05	-2.51E-05	-	-3.90E-05	101
After 2000Well	H	448/23	1.53E-04	-4.93E-06	-	-1.32E-05	91
	H+V	401/23	3.35E-04	-3.81E-06	3.14E-06	3.14E-06	90
	Scouring H+V	396/23	1.50E-04	-3.89E-06	-	-1.01E-05	91
Inter 1990 to 2000	H	708/23	1.11E-04	-4.84E-06	-	-1.08E-05	109
	H+V	712/23	1.13E-04	-4.23E-06	-	1.15E-05	70
	Scouring H+V	452/31	1.08E-04	-6.30E-06	-	-8.81E-07	98
Before 2000	H	378/23	2.85E-05	-7.78E-06	-	-1.13E-05	16
	H+V	418/23	-8.92E-06	2.85E-06	-	9.28E-06	4
	Scouring H+V	169/33	1.07E-04	-2.26E-05	-	2.85E-06	84

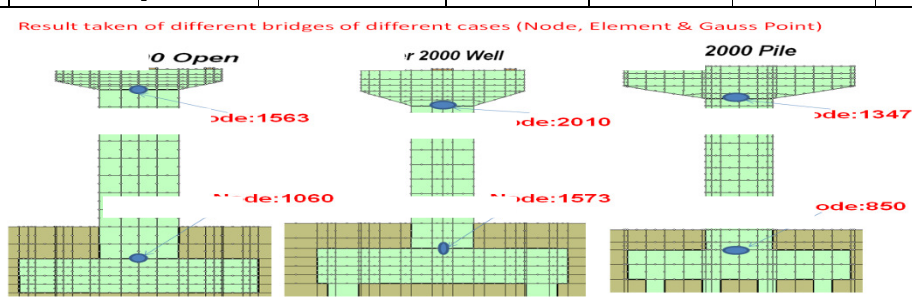


Figure-7: Location of Node Number After 2000 Open, Well and Pile.

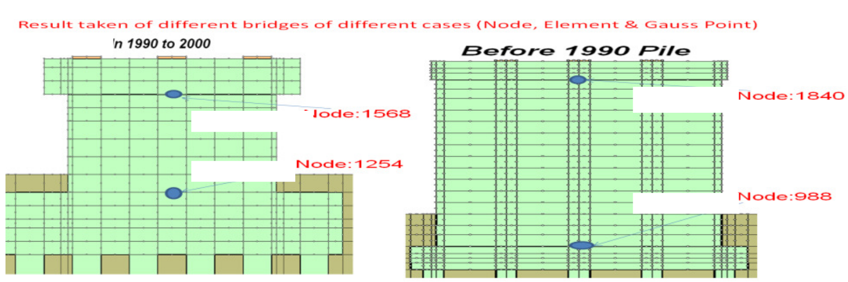


Figure-8: Location of Node Number in 1990-2000 Pile and Before 1990 Pile.

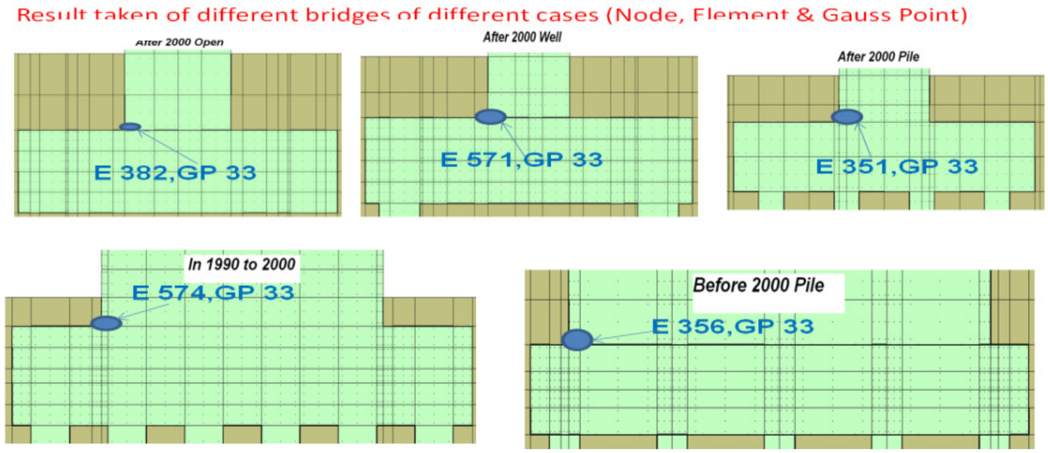


Figure-9: Location of Element and Gauss Point (Five Nepalese RC Bridge Pier).

Table-3: Length of Soil (Five Nepalese RC Bridge Pier).

After 2000 open				400 m	500 m	400 m	500 m	400 m
				AO	AW	AP	IP	BP
Description	300	350	400	% dif.	% dif.	% dif.	% dif.	% dif.
After 2000 Pile	6.72	6.68	6.659	0.15	0.02	0.08	0.06	0.1
After 2000Well	1.62	1.51	1.5	0.33	0.1	0.46	0.31	0.16
Inter 1990 to 2000	1690	1680	1675	0.15	0.05	0.01	0.02	0.25
Before 2000	79	76	75	0.34	0.25	0.23	0.2	0.4
Before 2000	0	4E-05	4E-05	0	0	0	0	0
Before 2000	0	3E-04	3E-04	0	0	0	0	0
Before 2000	0	7E-05	7E-05	0	0	0	0	0
Before 2000	0	7E-06	7E-06	0	0	0	0	0
Before 2000	0	3E-05	3E-05	0	0	0	0	0

Table-4: Structure Result after 2000 Open.

Description		H	HV	HVS
Displacement	Horizontal (Top) N1563 (cm)	6.659	7.288	13.47
	Vertical (Bottom) N1060 (cm)	1.5	2.702	2.370
Relative Acceleration N1563, N1060 (cm/sec^2)	Horizontal acceleration	1052	1096	1224
	Vertical acceleration	378	2012	1372
Gauss Point Result E382, GP33	Strain XX	3.64E-05	-0.00011	0.000059
	Strain YY	-0.000341	0.000618	-0.111224
	Strain XY	-6.97E-05	0.00069	-0.000319
Global Stain Result	Mean Strain	-7.25E-06	-2.2E-05	-2.32E-05
	Deviation Strain	2.69E-05	5.29E-05	6.89E-05

Table-5: Structure Result after 2000 Well.

Description		H	HV	HVS
Displacement	Horizontal (Top) N2010 (cm)	28.760	25.910	29.28
	Vertical (Bottom) N1573 (cm)	1.4	6.040	5.490
Relative Acceleration N2010, N1573 (cm/sec^2)	Horizontal acceleration	893	1163	1370
	Vertical acceleration	5	1695	2726
Gauss Point Result E571, GP33	Strain XX	1.61x1.0e-5	-1.204E-04	5.01x1.0e-5
	Strain YY	-1.77E+01	-6.857E+01	-5.369E+01
	Strain XY	-3.21E+01	-2.798E+01	-2.178E+01
Global Stain Result	Mean Strain	-2.90E+01	15.07x1.0e-5	4.45x1.0e-5
	Deviation Strain	67.59x1.0e-6	18.75x1.0e-5	10.50x1.0e-5
Structural Result Peak Strain damage Light damage Considerable damage Failure damage	Peak shear strain	1.34E-03	3.69E-03	2.56E-03, -5.08E-04, 1.30E-03
	Peak Tensile strain			
	Peak Compressive strain			
	Tensile strain normal to crack			
	Compressible strain parallel to crack			
	Shear strain parallel to crack			

Table-6: Structure Result after 2000 Pile.

Description		H	HV	HVS
Displacement	Horizontal (Top) N1347(cm)	25.880	13.670	23.35
	Vertical (Bottom) N850 (cm)	5.39	9.170	9.460
Relative Acceleration N1347, N850 (cm/sec^2)	Horizontal acceleration	1052	1096	1224
	Vertical acceleration	986	2312	3272
Gauss Point Result E351, GP33	Strain XX	1.87x1.0e-4	4.14x1.0e-4	1.86x1.0e-4
	Strain YY	-1.61E+01	-1.536E+01	21.14x1.0e-4
	Strain XY	-3.35E+01	42.75x1.0e-5	-2.014E+01
Global Stain Result	Mean Strain	-4.72E+01	-7.845E+01	-1.19E+01
	Deviation Strain	65.90x1.0e-6	81.61x1.0e-6	11.56x1.0e-5
Structural Result Peak Strain damage Light damage Considerable damage Failure damage	Peak shear strain	1.06E-03	3.69E-03	1.41E-03, -9.74E-03, -1.62E-02, -8.46E-02, -2.29E-02
	Peak Tensile strain			
	Peak Compressive strain			
	Tensile strain normal to crack			
	Compressible strain parallel to crack			
	Shear strain parallel to crack			

Table-7: Structure Result in 1990-2000 Pile.

Description		H	HV	HVS
Displacement	Horizontal (Top) N1347 (cm)	18.8	18.720	19.02
	Vertical (Bottom) N850 (cm)	0.71	2.710	3.666
Relative Acceleration N1568, N1254 (cm/sec^2)	Horizontal acceleration	967.5	1325	1953
	Vertical acceleration	44.3	1438	2811
Gauss Point Result E574, GP33	Strain XX	-5.39E+00	5.98x1.0e-5	1.84x1.0e-5
	Strain YY	10.81x1.0e-5	83.16x1.0e-5	-2.924E+01
	Strain XY	51.14x1.0e-6	65.96x1.0e-5	-1.667E+01
Global Stain Result	Mean Strain	-2.77E+01	-5.282E+01	-4.52E+01
	Deviation Strain	61.94x1.0e-6	70.14x1.0e-6	50.36x1.0e-6
Structural Result Peak Strain damage Light damage Considerable damage Failure damage	Peak shear strain	No damage No failure		
	Peak Tensile strain			
	Peak Compressive strain			
	Tensile strain normal to crack			
	Compressible strain parallel to crack			
	Shear strain parallel to crack			

Table-8: Structure Result before 1990 Pile.

Description		H	HV	HVS
Displacement	Horizontal (Top) N1347 (cm)	23.91	24.010	30.16
	Vertical (Bottom) N850 (cm)	1.07	2.750	3.230
Relative Acceleration N1840, N988 (cm/sec^2)	Horizontal acceleration	967.5	1325	1453
	Vertical acceleration	44.3	1438	1811
Gauss Point Result E356, GP33	Strain XX	8.83x1.0e-6	-5.740E+00	3.37x1.0e-5
	Strain YY	-5.54E+01	13.01x1.0e-4	-2.693E+01
	Strain XY	41.76x1.0e-7	33.14x1.0e-5	-5.416E+01
Global Stain Result	Mean Strain	-2.17E+07	-5.282E+01	-4.52E+01
	Deviation Strain	61.94x1.0e-6	70.14x1.0e-6	50.36x1.0e-6
Structural Result Peak Strain damage Light damage Considerable damage Failure damage	Peak shear strain	1.22E-03, 3.69E-03		
	Peak Tensile strain			
	Peak Compressive strain			
	Tensile strain normal to crack			
	Compressible strain parallel to crack			
	Shear strain parallel to crack			

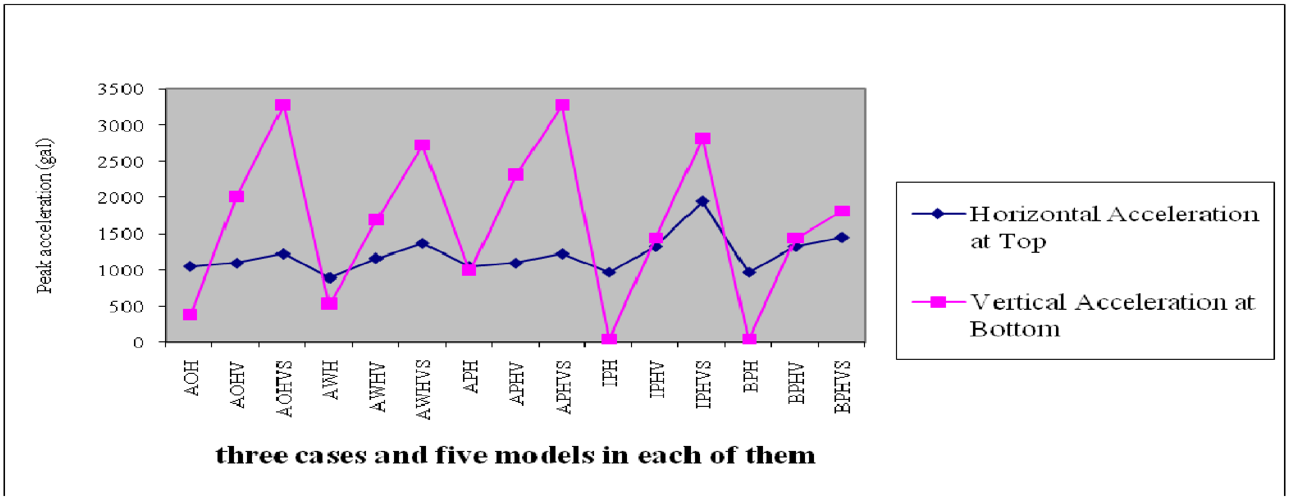


Figure-10: Peak Acceleration (cm/sec^2).

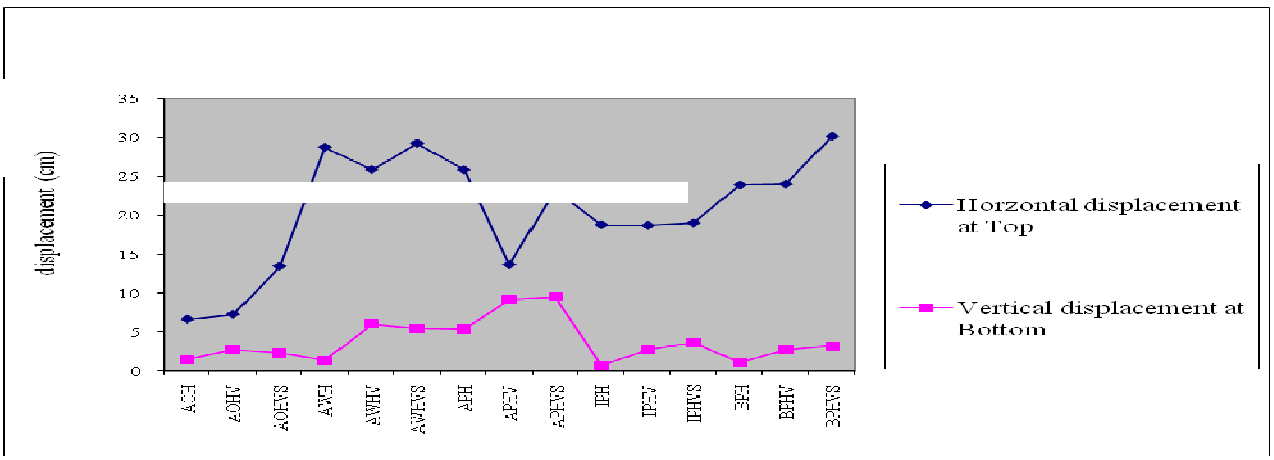


Figure-11: Peak displacement (cm).

The largest acceleration horizontal at top (IPHVS Case) and vertical at bottom (APHVS Case) (Figure-10). The absolute displacement is first largest for the case AWHVS and second largest for the case BPHVS (Figure-11).

Conclusion

This research shows that seismic performance of the typical Nepalese RC Bridge pier structures. The severe damage and possibility of collapse of the RC Bridge piers structures with very strong coupled vertical ground motion Gazali, Uzbekistan 1976. The conclusions drawn from this research is as follows.

The lateral extent of soil mass for each of the five different bridges were fixed based on trial computations until the percentage difference in consecutive response quantities were found within the limit of 0.4%. The lateral extent for the Bridge 1 (After 2000 Open) is fixed as 400m, Bridge 2 (After 2000 Well) is fixed as 500m, Bridge 3 (After 2000 Pile) is fixed as 400m, Bridge 4 (Inter. 1990-2000 Pile) is fixed as 500m and Bridge 5 (Before 1990 Pile) is fixed as 400m. The light damage, considerable damage and also failure damage of the Bridge pier at different bridges for different cases (After 2000 Open, After 2000 Pile, After 2000 Well and Before 1990). The introduction of strong vertical ground motion increase the vertical displacement by 48% all bridges. It means horizontal ground acceleration (0.71g) and vertical ground acceleration (1.37g) both applied horizontal displacement increases as well as vertical displacement increases. First crack all bridge for different cases. The Nepalese RC Bridge Pier (After 2000 and Before 1990) is designed under safe.

Acknowledgement

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Appendix-I

Table-9: Structural Components and their characteristics.

Description	Percentage of Steel				Width (m)			Depth (m)			
	Pier cap	Pier	Pile cap	Pile	cap	Pier	Pile cap	Pier cap	Pier	Pile cap	Pile
After 2000 Open	2.33	2.03	1.13	-	3.9	2.3	2.25	1	10	2.25	-
After 2000 Well	0.76	2.68	1.18	1.58	3.9	1.5	1.2	1.2	4.9	1.2	13.3
After 2000 Pile	0.85	2.53	1.14	1.76	6.2	1.8	1.2	1.3	6.1	1.2	20
1990-2000 Pile	0.63	2.26	2.44	2.53	5.6	5.3	1.4	0.8	3	1.4	9.77
Before 1990 Pile	0.3	0.8	0.68	2.19	5.7	5.4	1	0.8	7.2	1	12.7

Appendix-II

Table-10: Soil Profile and its characteristics.

Parameters	Unit	After 2000, 1990-2000, Before 1990	
		Open, Well, Pile	
		Layer I	Layer II
Layer Thickness	m	3.5	21.5
Soil Type		Sand	Sand and Clay
SPT N		7	12
Unit Weight	KN/m^3	18	
Poisson Ratio		0.3	
Go	N/mm^2	56	86
Eo	N/mm^2	145	223
Su	N/mm^2	0.051	0.101
Shear Velocity	m/s	174	216

Appendix-III

Table-11: Static load on pier from superstructure.

Description	Types of lane	Span (m)	Super Structure Load		Total Load on pier from superstructure (KN)
			Self. Weight (KN)	Live Load (KN) including impact	
After 2000 Open	Single	18	1362.4	601.40	1963.80
After 2000 Well	Single	18	1362.4	601.40	1963.80
After 2000 Pile	Double	21.7	1880.1	1134.4	3014.5
Int. 1990 to 2000	Double	22.64	1961.54	1183.54	3145.08
Before 1990	Double	18.27	1582.93	955.09	2538.02

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