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STUDY ON RETROFITTING OF OLD REINFORCE CONCRETE BRIDGE

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ABSTRACT: Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it. Selecting the appropriate treatment strategy is a great challenge involved in the retrofit process and must be determined individually for each project. Depending on project objectives, preservation and renovation of buildings may involve an array of diverse technical considerations, such as fire life safety, geotechnical hazards and remedies, weathering and water infiltration, structural performance under earthquake and wind loads. The analysis was performed in Staad pro V8i with reference of experimental values. The varying stiffness produced a variation in the lateral displacement of 20%, but the longitudinal ductility range was less than 10%. For the transverse direction, the variation in displacements was within 12% and the ductility values remained close, the shear reaction of the structure could be reduced by 25%, while its displacement change was less than 10%. Therefore, the overall change in the displacement due to the presence of varying foundation stiffness is minimal compared to the force demand reduction caused by softer foundations, Short spanned reinforced concrete bridges show that in translational vibration the greatest mass participation ratios are usually associated with the fundamental vibration modes. The superstructure tends to move as a unit both in longitudinal and transverse directions and the influence of higher vibration modes is negligible the IBC code (2000) & IS 1893:2002 codes are used in simulation to analyze the performance of RC bridge structure.
Keywords: Retrofitting, RC Bridge, Finite Element Analysis, Vibration analysis, Displacement, Columns

I. METHODOLOGY & EXPERIMENTAL INVESTIGATION

FINITE ELEMENT ANALYSIS (FEA)

FEA stands for Finite Element Analysis and as the name propose the method entails the analysis of finite elements. The entire version is split into wide variety of finite factors and then all of the forces and boundary conditions are applied on these finite elements, and then the consequences of a majority of these finite factors are mixed together to provide the output of entire model. For example if a line is representing a beam and we've got to research that beam as a cantilever then FEA will divide this line representing a beam into number of small segments called detail. Then the impact of boundary condition and forces is studied on each segment and the consequent output is the summation of each phase. FEA analysis can assist engineers to research complex fashions. With the development of laptop systems FEA has accelerated to advantage importance, because it saves time and money both.

PROCEDURE FOR FINITE ELEMENT ANALYSIS

Consider the instance of an vehicle piston. A piston all through the operation of I.C Engine is subjected to diverse styles of hundreds like effect load, friction force and reaction from cylinder wall due to thermal expansion of piston and so forth. Due to those masses, a non-uniform pressure distribution may additionally take in the piston frame. This nature of stress distribution can be determined using finite detail analysis approach, in which the entire frame of the piston is split into smaller elements referred to as finite factors. These factors may be rectangular, cuboidal, tetrahedral, prism or hexahedral factors. These elements are connected to every other at nook vertices (or nodes). Element matrices are described to locate the cost of stresses at those nodes. Then a global stress matrix is defined which represents the pressure distribution in complete frame of the piston. Once the stress distribution in the entire frame of piston is known, design upgrades can be made by means of increasing wall thickness in the vicinity of higher pressure accumulation. Finite element technique is a numerical analysis method and is used to locate variables. These discipline variables may be vector portions like displacement, stress, and so forth. Or scalar portions like distance, temperature and so on.

Any analysis to be carried out by using finite detail method can be divided into following steps:

- Discretization
- Applications of subject/boundary conditions
- Assembling the gadget equations
- Solution for the system equations

DISCRETIZATION

In this step entire frame is to be analyzed is divided into smaller elements or finite factors. These elements are related to each other through nodes. The factors have to now not overlap each other. Dividing the body into elements and nodes is called mesh technology or meshing. For example take a cantilever beam and divide that beam into six small elements. These factors have cubic shape. The corner factors of the factors are referred to as nodes. The finite factors are numbered from 1 to 6. The factors are interconnected by at to nodes in which the elements meet and pass in unison. In this situation cantilever is discredited into 6 elements only. But for better estimation of pressure distribution in the cantilever, the range of area factors need to be higher. Higher the variety of finite factors higher is the estimation of subject variables. The finite factors are labeled by way of:

(a) Family
(b) Order
(c) Topology

APPLICATIONS OF FIELD/BOUNDARY CONDITIONS

Once the discretization is carried out, we will include the recognized area/boundary situations which shall function reference and assist us in solving for the unknowns.

ASSEMBLING THE SYSTEM EQUATIONS

Once the reference or recognised conditions are imposed, we will outline units of equations which might be appropriate to outline the behaviour of the machine. This involves formulation of respective feature equation matrices.

SOLUTION FOR THE SYSTEM EQUATIONS

Once the equations are set we shall remedy the equal to recognise the unknowns and get insight into system behavior. That is basically the systems of matrices which are not anything but a set of simultaneous equations are solved.

REVIEW OF RESULTS

Upon the completion of answer, we will overview the results.

NODES

Nodes are the corner factor wherein factors are linked to each different. Element form can be modified with the aid of transferring a node in space.

ELEMENTS

Element is an entity, into which a device is discriterized. The form (Area, length and volume) detail depends upon the nodes with which it's miles made up of.

TEST RESULT

In both the longitudinal and the transverse directions, the fundamental periods were short. Movement associated with large system masses tended to concentrate in one mode in each direction. Therefore, higher mode effects were assumed to be negligible. Pushover loadings were applied based on the modes that associated with the largest mass participation ratio.

Table 4.1 Periods and mass participation ratios of models with varying parameters

Model		Mode number	Period with the largest mass participation (s)	Mass excited in longitudinal direction	Mass excited in transverse direction
Baseline model		3	0.43	97.78%	0
		1	0.63	0	97.49%
Abutment rotation restrained		3	0.35	96.37%	0
		1	0.51	0	97.56%
Fixed-end foundation		3	0.4	97.21%	0
		1	0.53	0	96.23%
Soft foundation model		1	0.76	96.93%	0
		3	0.46	0	97.81%
Pinned-end foundation model		3	0.43	97.65%	0
		1	0.59	0	97.92%
Varying abutment longitudinal spring stiffness	Link 1	1	0.83	97.90%	0
		2	0.74	0	97.57%
	Link 2	1	0.82	97.90%	0
		2	0.74	0	97.57%
Varying abutment transverse spring stiffness	Link 1	2	0.82	97.90%	0
		3	0.74	0	97.57%
	Link 2	1	0.83	96.39%	0
		2	0.74	0	97.57%
	Link 3	3	0.82	97.90%	0
		1	0.74	0	97.57%

II. VALIDATION OF MODELING ASSUMPTIONS

It was assumed that the influence of the rotational restraints of the abutment might be ignored. To validate the assumption that the abutments may be modeled as free of rotation restraints, cases had been compared. In the primary case the rotation of abutments turned into fully restricted, and in the 2nd case the abutments had no rotational stiffness. It can be seen from the results shown in figure 4.1 and 4.2 that the rotational spring stiffness had little effect on the response of the bridge when comparing the displacement at the monitored point resulting from the two models.

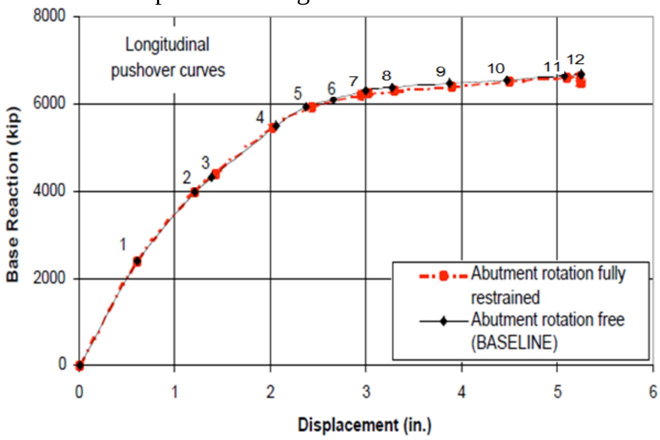

Figure4.1 Longitudinal pushover curves of abutment rotation restraints test

Table 4.2Longitudinal pushover curves of abutment rotation restraints test

Longitudinal Pushover Curves		
Displacement	Base Reaction (kip)	
	Abutment Rotation Free	Abutment Rotation Fully Restrained
1	2400	2400
2	3900	4000
3	4200	4300
4	5350	5400
5	5900	5900
6	6050	6100
7	6150	6200
8	6250	6300
9	6400	6500
10	6550	6600
11	6650	6700
12	6600	6750

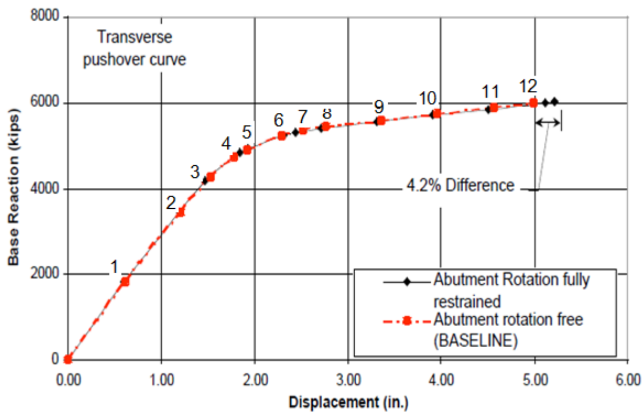

Figure 4.2Transverse pushover curves of abutment rotation restraints test

Table 4.3Transverse pushover curves of abutment rotation restraints test

Transverse Pushover Curves		
Displacement	Base Reaction (kip)	
	Abutment Rotation Free	Abutment Rotation Fully Restrained
1	1900	1900
2	3500	3500
3	4200	4100
4	4900	4800
5	5100	5100
6	5300	5200
7	5400	5300
8	5600	5500
9	5700	5600
10	5800	5750
11	5900	5800
12	6000	6000

In the longitudinal direction, the two pushover curves had been equal. But transverse-sensible, the shape tended to have a slightly larger displacement if the abutments had been rotationally constrained. If the abutment ought to rotate freely, the transverse displacement was reduced 4.2%. This can be explained by Figure 4.2, in which the dashed lines are the exaggerated deflection shapes of the superstructure under transverse modal loading.

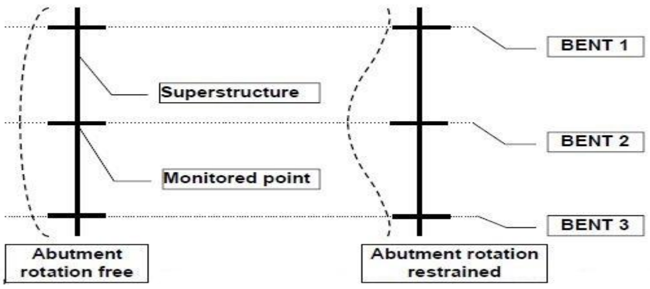

Figure 4.3 Plan view of the deflection shapes of the superstructure with different abutment restraints

In both cases in spite of the influence of the abutment rotation, the largest displacement alongside the superstructure took place at the pinnacle of the Bent 2. By looking at the collapse modes of the structure, it has been located that the bridge failed within the transverse direction because of hinge degradation at Bent 3. So the displacement of the pinnacle of the columns at Bent 3 managed the failure of the shape. In the rotation-constrained version, the displacement at the top of Bent 1 and Bent three were reduced because of the restraints from the abutments in Figure 4.3. In result, the rotation-constrained abutments allowed the Bent 2 to displace further transversely by way of postponing the Bent 3 to reach its rotation potential.

Compared to the transverse displacement of the complete superstructure, the version of the displacement at different bents shapes was very small. Therefore the rotational effects at the abutments can be ignored. This conclusion was supported by the fact that the same failure mechanism and the same sequence of the hinge yielding occurred in these two cases. Thus, the assumption is verified and in the following study no rotational springs were allotted to abutments

III. RESULTS ANALYSIS OF DRY WASH PUSHOVER

Longitudinal Pushover Results of Dry Wash and Explanations

Figure 4.3 shows the longitudinal Pushover curve of the baseline version of Dry Wash Bridge overlaid by way of the single call for spectrum with variable damping. The demand spectrum turned into produced with the belief that the bridge turned into inside the seismic.

Design category B as defined inside the IBC code (2000) & IS 1893:2002. The ultimate point at the pushover curve is seemed because the ultimate capability point, which suggests a displacement of 5.24 inches, and a base force is 6678 kips. The single demand spectrum intersectedwith the pushover curve at the performance point (2.171 in., 5656kip). That means that a design level earthquake (B category) is expected to impose a displacement of 2.171 inches in this structure, which is 41.4% of its longitudinal displacement capacity.

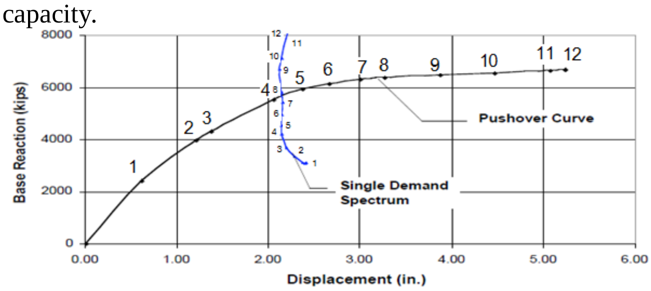

Figure 4.4 Longitudinal pushover curve of Dry Wash Bridge

Table 4.4 Longitudinal pushover curve of Dry Wash Bridge

Longitudinal		
Displacement	Base Reaction (kip)	
	Pushover Curve	Single Demand Spectrum
1	2500	3000
2	4000	3500
3	4300	3800
4	5200	4200
5	5900	4500
6	6200	5000
7	6300	5300
8	6400	5800
9	6500	6800
10	6600	7000
11	6800	7100
12	6850	7250

The Dry Wash consists of nine columns, three columns at each bent. Eighteen plastic hinges were pre-assigned in the model. The formation of plastic hinges turned into in series proven in Figure 4.4 on a step-to-step foundation. Some of the plastic hinges yielded concurrently at a selected pushover step. The pushover curves do no longer gift a completely obvious yielding plateau because the hinges on multi-columns provided a continuous redundancy for the structure to avoid immediate strength losses.

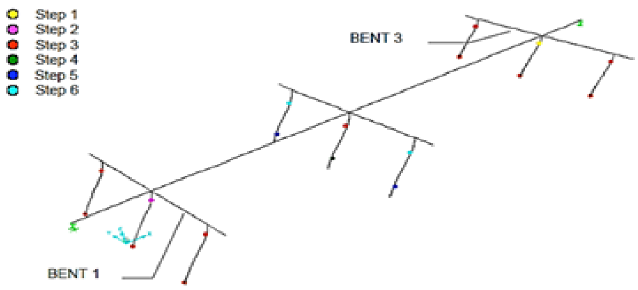

Figure 4.5 Dry Wash longitudinal pushover deflection and plastic hinges yielding sequence

The hinge at the top of the Middle column at Bent three became the first yielded hinge. All of the plastic hinges yielded, and the shape continued to push similarly till the final step, when hinges at the pinnacle of the middle columns at Bent 3 and Bent 1 failed as their rotation capacity have been handed and 11 hinges were over their Life Safety level. As a end result, the structure failed due to worldwide instability. Table 4.4 indicates the hinge statuses at yielding and ultimate step, wherein A, B, C, D, E are factors defining the instant-rotation courting, and the Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) are performance ranges. Note that in defining the performance stage on this look at, the CP factor was described because the identical factor C. Point D represents the equal rotation capacity with point C but with 80% strength degradation. So CP, C and D are on the equal point on the moment-rotation relationship in this study.

Table 4.5 Hinge statuses Dry Wash Bridge at different steps in longitudinal pushover procedure

Steps	Displacement (in.)	Base Forces (kips)	A-B	B-IO	IO-LS	LS-CP	CP-C-D	D-E	>E	Total
Initial Step	0.02	0	18	0	0	0	0	0	0	18
Yield Step	1.38	4312.83	17	1	0	0	0	0	0	18
Ultimate Step	5.24	6678.31	0	0	13	4	1	0	0	18

At the initial step the bridge displaced underneathit's self-weight. The displacement of 0.02 inches proven within the preliminary step is the thing displacement along the longitudinal direction of the bridge. Behavior of hinges beneath self-weight changed into still in linear range.

The yield factor of the structure turned into described as the factor whilst the primary yield befell at certainly one of plastic hinges, that's indicated within the table because the repute of "B-IO". A Capacity Spectrum of longitudinal pushover is proven in Figure 4.5. On the spectrum vicinity, capacity spectrum and call for spectrum have been plotted inside the spectral acceleration versus spectral displacement coordinates. The blue line is the single demand spectra with variable damping, and the red lines are demand spectra with different damping ratios.

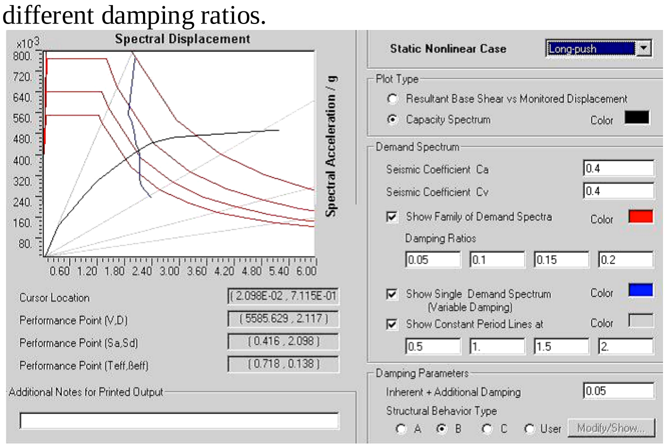

Figure 4.6 Longitudinal Capacity spectrum of Dry Wash.

TRANSVERSE PUSHOVER RESULTS OF DRY WASH AND EXPLANATIONS

In the transverse direction, the structure presented less displacement capacity compared to the longitudinal direction. It was assumed that the same seismic design category, B category, generated the single demand spectrum. The ultimate displacement was 5.00 inches, and the performance point was at (2.260in, 5226kip). So a design level earthquake can cause a displacement of 2.260 inches at the monitored point, which consumes 45.2% transverse displacement capacity of the bridge.

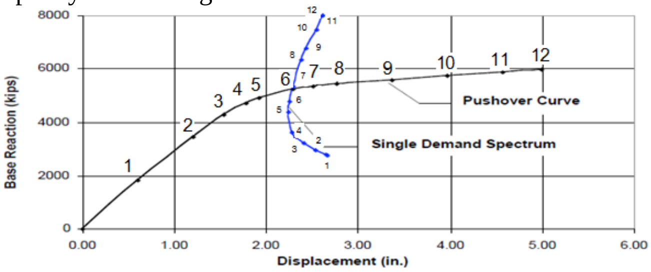

Figure 4.7 Pushover curve for Dry Wash Bridge on transverse direction

Table 4.6 Pushover curve for Dry Wash Bridge on transverse direction

Displacement	Transverse	
	Base Reaction (kip)	
	Pushover Curve	Single Demand Spectrum
1	1900	2900
2	3600	3000
3	4200	3100
4	4900	3500
5	5000	4500
6	5200	5000
7	5300	5200
8	5400	6100
9	5500	6700
10	5700	7100
11	5800	8000
12	5950	8100

The hinges yielded in six steps shown in Figure. It has been observed that hinges at the edge bent yielded before those at the centre bent. Hinges at the top of columns at Bent 3 yielded firstly.

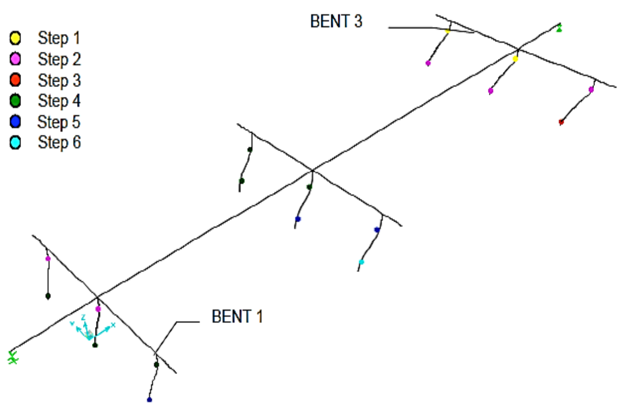

Figure 4.8 Dry Wash transverse deflection shape and plastic hinges yielding sequence

After the bridge displaced to its maximum capacity on the transverse direction, global instability was formed and the structure failed. The hinges statuses at yield and ultimate step are shown in Table 4.7

Table 4.7 Hinge statuses of Dry Wash Bridge at different steps in transverse pushover procedure

Steps	Displacement (in.)	Base Forces (kips)	A-B	B-IO	IO-LS	LS-CP	CP-C-D	D-E	> E	Total
Initial Step	0.005	0	18	0	0	0	0	0	0	18
Yield Step	1.53	4373.93	16	2	0	0	0	0	0	0
Ultimate Step	5.00	5991.12	0	0	10	7	1	0	0	18

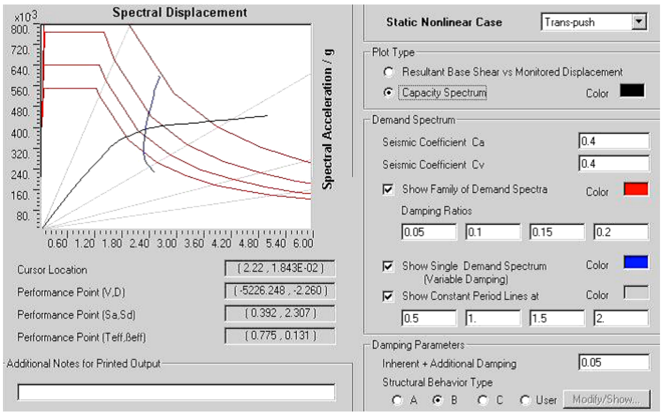

Figure 4.9 Transverse capacity spectrum of Dry Wash

IV. STRUCTURAL DUCTILITY

Table 4.9 compares the pushover curves and the relative places of the overall performance factors on the curves. It can be visible that the bridge becomes slightly much less stiff in the transverse route than the longitudinal course. This is due to Dry Wash Bridge being better engaged with the again wall on the abutment than with the wing wall in which the contact area with the soil was small.

GENERAL

The results from this study indicate that retrofit strategies of reinforced concrete bridges can be optimized to achieve the performance goals of a given structure. As a result, considerable economic savings can be realized in retrofitting applications. Short spanned reinforced concrete bridges show that in translational vibration the greatest mass participation ratios are usually associated with the fundamental vibration modes. The superstructure tends to move as a unit both in longitudinal and transverse directions and the influence of higher vibration modes is negligible. Bridge abutment rotational constraints do not have much influence on the deflection of the superstructure for this type of bridge.

- Retrofitting applications on bridge footings can stiffen or soften the connection between the footing and soils. Bridges supported by softer foundations can tolerate larger displacements; however, due to the change in the seismic demand, the performance ductility varies but not necessarily increasing as the foundations are softened.
- That is due to the increases in the maximum and performance displacements not necessarily being proportional. It has been found that for the longitudinal direction, the varying stiffness produced a variation in the lateral displacement of 20%, but the longitudinal ductility range was less than 10%. For the transverse direction, the variation in displacements was within 12% and the ductility values remained close.
- Force input to the structure can vary greatly due to the change in the foundation properties, especially in the transverse direction. By softening the baseline foundation properties to a practical level, the shear reaction of the structure could be reduced by 25%, while its displacement change was less than 10%. Therefore, the overall change in the displacement due to the presence of varying foundation stiffness is minimal compared to the force demand reduction caused by softer foundations.
- A flexible foundation connection is recommended for this type of bridge to reduce the force demand, as the ductility of the structure remains almost the same. For other types of bridges, analysis should be performed to estimate the “trade-off” of ductility and force demand reduction.
- The transverse response of a bridge relies more on the framing effect of piers than single column and abutments, so foundation properties tend to have a larger influence.
- In contrast, variable abutment properties have larger influence on the longitudinal stiffness than on the transverse stiffness of the structure. For both directions, the displacement variation associated with abutment stiffness change is very small.
- Therefore, retrofit techniques for bridge abutment aimed at increasing the stiffness may result in little improvement on the global structure displacement capacity. They will, however, induce a great force demand on the structure. For this type of bridges, retrofitting applications that increase the locking of the abutment and the soils should be avoided.
- Steel jacketing presents the best approach to improve the bridge ductility. By comparing results from eighteen analysis cases, it is concluded that middle columns and columns with shorter effective height are the most critical for improving the bridge longitudinal ductility. For the transverse direction, priority in retrofitting should be given to shorter columns because similar displacements at the top of the columns indicate larger drift ratios.
- It should be noted that it is the effective height rather than the physical height of the column that is used to estimate the vulnerability. The effective height of a column can be changed by changing its boundary conditions. A deep embedded column that allows an in ground plastic hinge to occur can be retrofitted by elongating their effective length. The column would rotate around the plastic hinge rather than the end of the column. Retrofitting methods exist to isolate the surrounding soils from the columns so that the effective height is increase and a more flexible boundary condition is created.
- Analytical research may be conducted to better understand the performance of a bridge prior to the implementation of retrofitting plans. Bridges may

perform well in one direction, while exhibiting poor response in the other direction. The Dry Wash Bridge has better ductility in the longitudinal direction, so the retrofitting plans should be more focused in the transverse direction.

- By attaching more importance to the columns with shorter effective lengths and as well as the middle columns, two column combination plans were recommended to retrofit the Dry Wash Bridge.
- One is to jacket the three columns at the right edge bent and the middle column at the left edge bent. The longitudinal and transverse displacement capacities can increase by 13.6% and 28.5% respectively. The other is to jacket six columns, which consist of three columns at the left edge bent, the middle column at centre bent, and the two columns at the right edge bent. This plan can produce 21.6% and 42.5% increases in the longitudinal and transverse displacements respectively.

FUTURE SCOPE

- The retrofitting could be done by using polymer concrete for strengthening the weaker section of columns
- CFRP (Carbon fibre reinforced polymer) layer would be imposed in surface of column to increase frequency against seismic effects.
- Polymer element with spring would be inserted below the column to improve its strength.
- Several parameters could be analyzed for retrofitting by using analysis software like STAAD PRO V8i and ANSYS CIVIL and E - TAB.

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