SEISMIC STRENGTHENING OF BRIDGES

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INTRODUCTION

Occurrence of earthquake is no more a rare eventuality. India has witnessed several major earthquakes, involving substantial loss of lives. To name a few, a major earthquake (Richter scale 8.5) occurred in Assam in 1897 wherein the reported death toll was 1500. It was repeated at the same place in 1950 with similar number of reported deaths. Similarly in 1934 major earthquake (Richter scale 8.4) occurred in Bihar-Nepal area claiming 14,000 lives. It was repeated in 1988 claiming about 1000 lives. The most recent major earthquake (Richter scale 8.0) in Bhuj claimed over 20,000 lives. By and far, major earthquakes have been observed to repeat in about 50 years in high earthquake prone areas.

Comparatively, a larger number of bridges have been affected by seismic activities in America and Japan than those in India. Latur earthquake in 1993 did wake up the authorities to survey the bridges in Maharashtra area, retrofit and rehabilitate those bridges. Golden Gate Suspension Bridge, San Fransisco has been another example of Earthquake Retrofitting. Technique of retrofitting is not unique or predefined. It has to be decided on case to case basis, depending upon the prevailing circumstances.

OBSERVED DAMAGES

Quite often, damage is noticed in and around the bearings due to stress concentration at these locations. Fig.1 shows an example of such damages even in a newly constructed bridge. Bearing has always been said to be a week link between massive superstructure and the substructure. Similarly Fig. 2 shows that the superstructure of another bridge pounded the dirt wall, due to excessive longitudinal movement.

Fig. 1: Damage at bearing level in new Surajbari Bridge

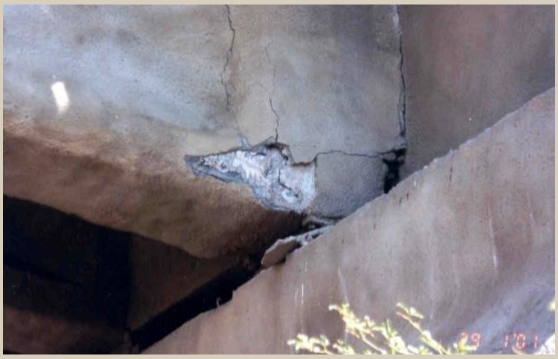

Fig. 2: Macchu Bridge superstructure pounded the dirt wall

Fig. 3 shows damage of short vertical cantilever attached to the pier cap provided to negotiate difference of depths of the two adjoining superstructures. This happens due to formation of plastic hinges and lack of dissipation of earthquake energy at these locations.

Fig. 3: Bridge between Surajbari and Bhachau

Similarly, Fig. 4 shows damages of L-shaped superstructure at the half joints provided to house the hinge bearing.

Fig. 4: Surajbari old bridge half joint in distress due to vertical and horizontal shaking

SEISMIC STRENGTHENING

Possible causes of deficiency in a bridge can be broadly the following:

- Inadequate Design
- Lack of Understanding by the Designer
- Inadequate Construction
- Deterioration of Material with Time
- Upgradation of Seismic Design Requirements
- Upgradation of Seismic Zones

Therefore, main requirements of the proposed strengthening are as follows:

- Should be Economically Feasible
- Should be Technically Viable
- Should Surmount Functional Constraints
- Should Reduce Seismic Demand
  - Reduce SILD and LL
  - Reduce Stiffness – Saw Cutting of Parapet
- Increase Dissipation of Seismic Energy
- Dampers
- Increase the Supply Strength
- Structural Strengthening

Seismic forces cause plastic hinge formation and overstressing at specified locations, such as pier- foundation junction, pier-superstructure junction in case of integral bridge, etc. For all such conditions, the pier cap can be confined to substantially enhance the performance during ultimate load conditions, see Figs. 5 and 6.

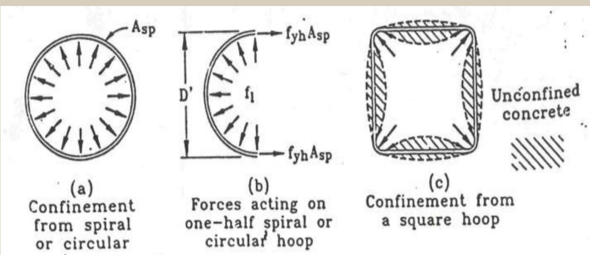

Fig. 5: Confinement of concrete by circular and square hoops

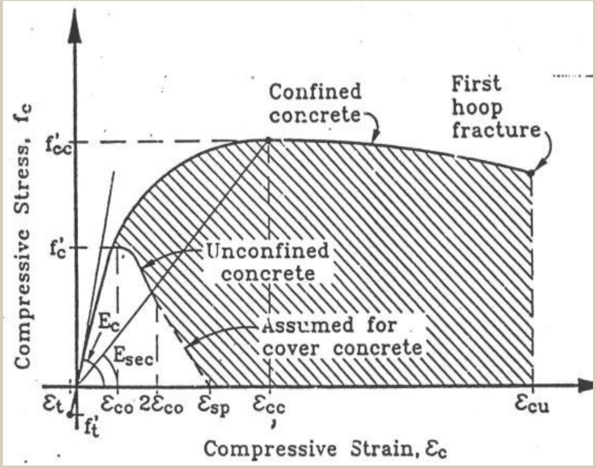

Fig. 6: Stress-strain model for concrete in compression

The Figs. 7 and 8 below depict detailing for strength enhancement through addition of steel and concrete respectively. The additional concrete of the pier needs to be adequately anchored to the corresponding foundation.

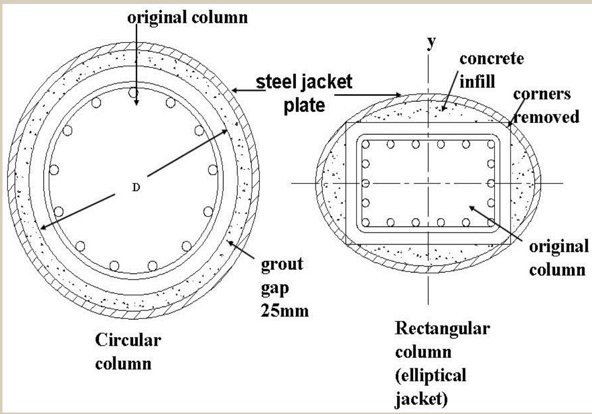

Fig. 7: Confinement of columns by steel jacketing

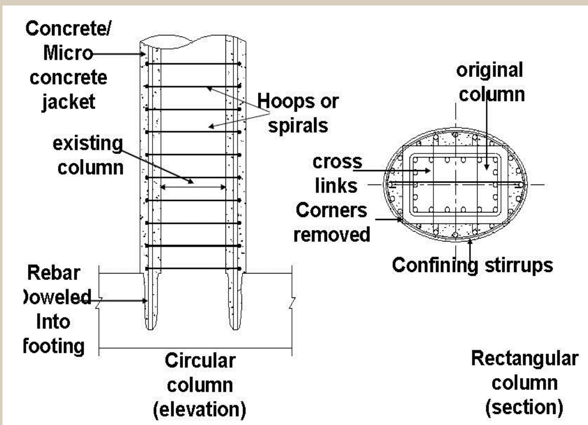

Fig. 8: Confinement of columns by concrete jacketing

Concrete portals are commonly connected to the superstructure either through bearings or integrally. In such cases, the seismic force carrying capacity of a portal can be enhanced as depicted in Figs. 9 and 10.

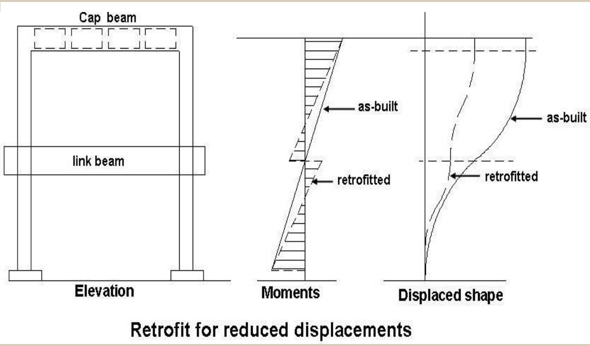

Fig. 9: Use of link beam to improve transverse seismic response of multi-column bents

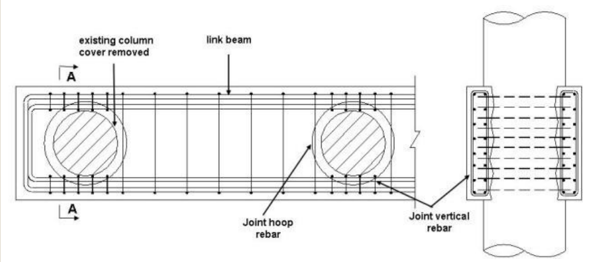

Fig. 10: Retrofit using link beams

In the seismic conditions, foundations need to be strengthened both for downward load and uplift. Fig. 11 depicts the use of additional piles to increase downward load capacity of pile foundation and the use of Passive Ground Anchors for prevention against uplift. Fig. 12 depicts increase of structural strength of foundation by additional concrete and addition of prestressing after drilling hole into the foundation and grouting it after the application of prestress.

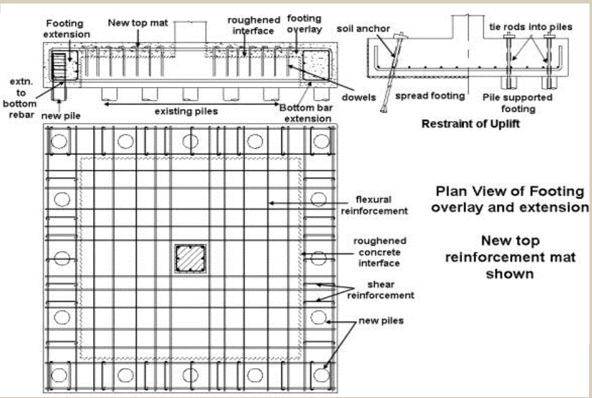

Fig. 11: Footing retrofit measures

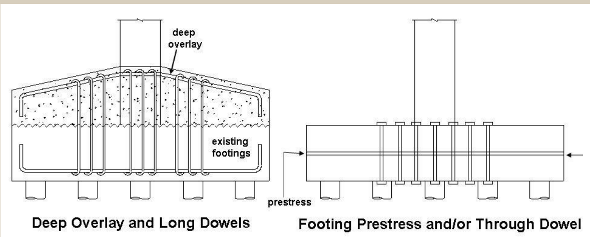

Fig. 12: Retrofit measures for joint shear stress deficiencies

Reinforcement couplers and rebar fasteners are very useful components for enhancing the strength of an existing structures. Existing reinforcement can be suitably extended by providing reinforcement couplers, see Fig 13. In case, new reinforcing bars have to be added, rebar fasteners can be provided by drilling a hole of specified diameter and depth in concrete and filling high strength resin before inserting reinforcing bar, see Fig. 14. This way full strength of the bar can be achieved.

Fig. 13: Reinforcement couplers

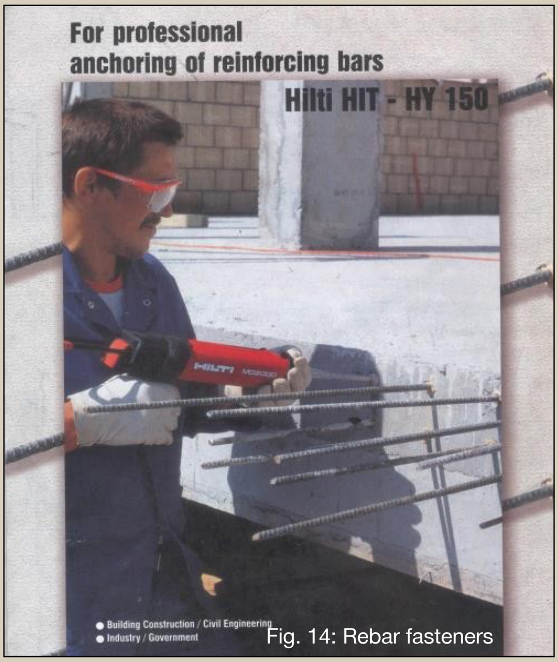

Fig. 14: Rebar fasteners

In case a well foundation has to be strengthened, it can be done in the manner depicted in Fig. 15. In case a masonry pier/abutment has to be increased in dimension, it can be done in the manner depicted in Fig. 16.

In many cases, wing walls are found to be bulged out due to seismic movement of the earthfill behind the wing wall. In such cases, solution lies in providing prestressing force to restore the wing wall as shown in Figs. 17 & 18.

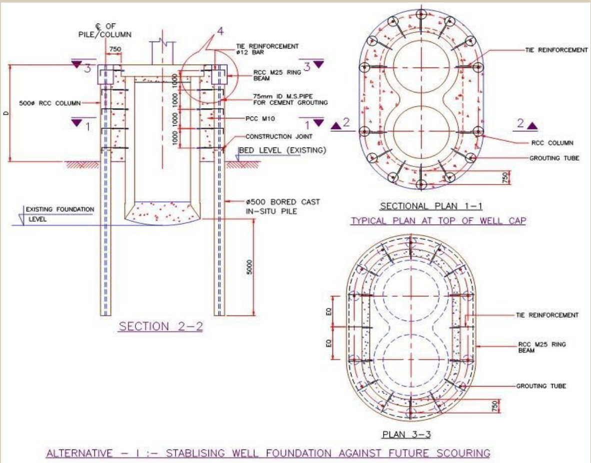

Fig. 15: Strengthening of well foundation

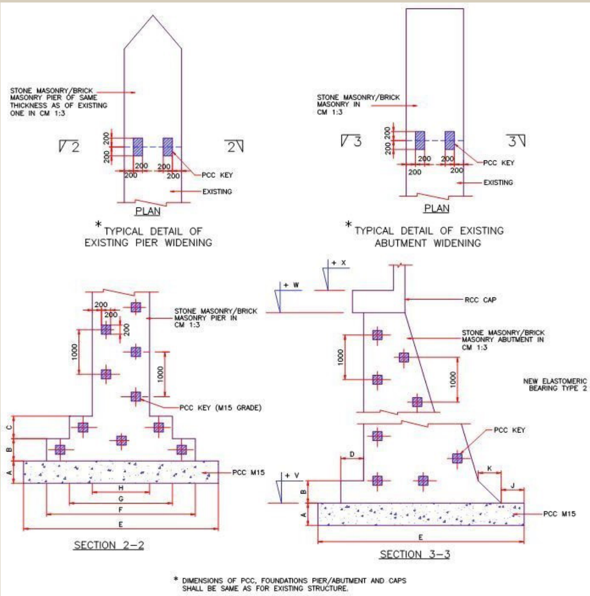

Fig. 16: Widening of masonary pier & abutment using shear keys

In these cases, the operation is performed in two parts, (one half road width at a time). After removing the road crust, a 300 mm dia CI pipe with coupling flanges is placed. Thereafter, RCC is added (along with necessary shear connectors) to increase the section of the wing wall and the size of its footing. Now, prestressing wire/strands encased in HDPE tube are inserted into the CI pipe and prestessed and subsequently grouted.

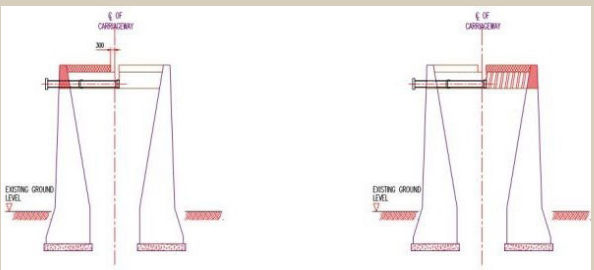

Fig. 17: Scheme for strengthening of moved wing wall

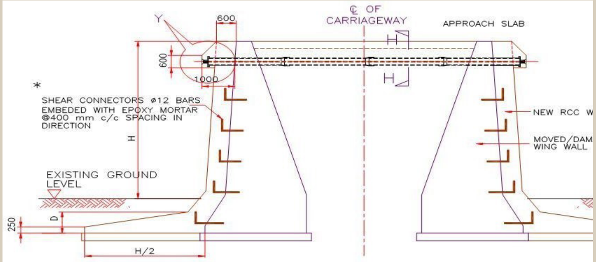

Fig. 18: Scheme for strengthening of moved wing wall

Seismic forces experienced by the bridge can be substantially reduced by addition of vertical concrete upstands from the pier/abutment cap and sandwitching flexible material, such as elastomer. Figs. 19 and 20 depict the system of such an arrangement.

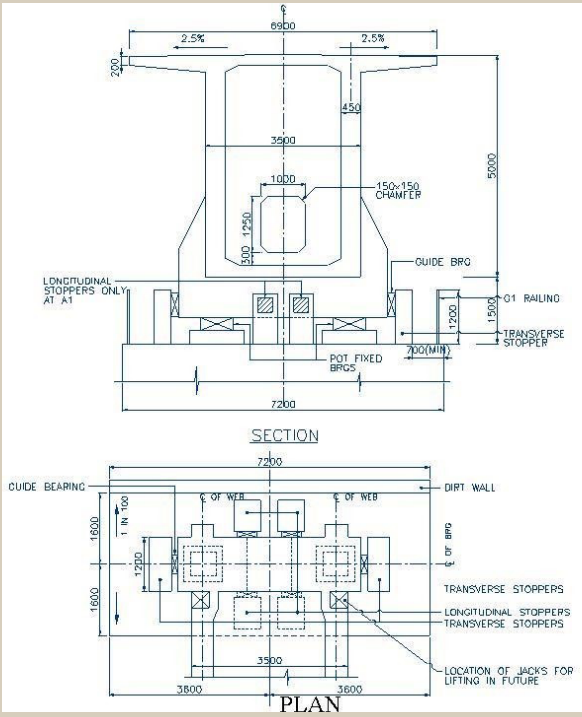

Fig. 19: Seismic restraint devices over abutement

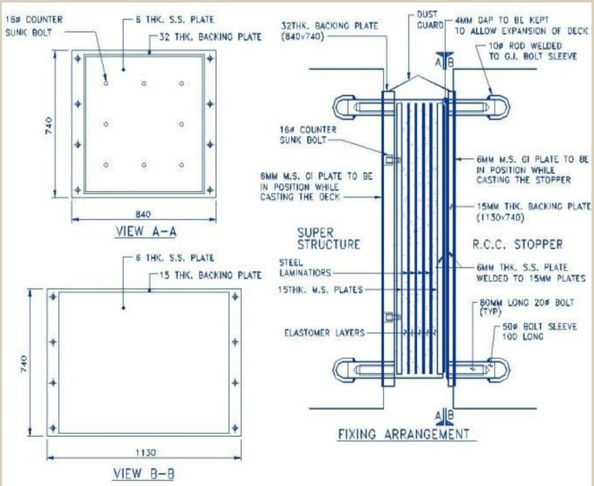

Fig. 20: Vertically positioned elastomeric bearings

In this arrangement the vertical elastomeric bearings need to be detailed in a specialized way, wherein, the mating surface between the fixed side and the moveable side is made into stainless steel, in order to reduce sliding friction. For anchoring purpose a mild steel plate vulcanized on the surface of the bearing, as shown in Fig. 20 is provided. Figs. 21 & 22 depict an isometric view and photograph of such concrete up stands that receive the vertical elastomeric bearings. The elastomer acts as isolator by substantially increasing time period of the structure, thereby reducing the seismic forces experienced by the structure.

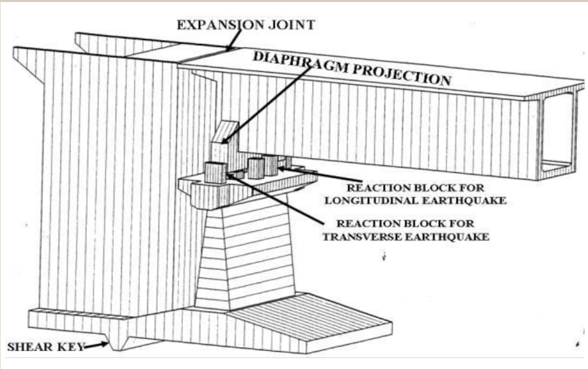

Fig. 21: Details at restrained bearing over abutment

Fig. 21: Details at restrained bearing over abutment

The other method of strength enhancement is to provide fiber wraps. Mainly there are Carbon Fiber Wraps and Glass Fiber Wraps. These fiber wraps exhibit low creep and elongation and compared to steel, they are thinner, lighter and have up to 10 times and tensile strength capacity. Since, these wraps have unidirectional tensile capacity, they have to be carefully provided in the direction, strength enhancement is desired. Incase both shear and flexural strengths are required, two layers of the wrap perpendicular to each other are provided, refer Figs. 23 and 24 for examples of fiber wrap application.

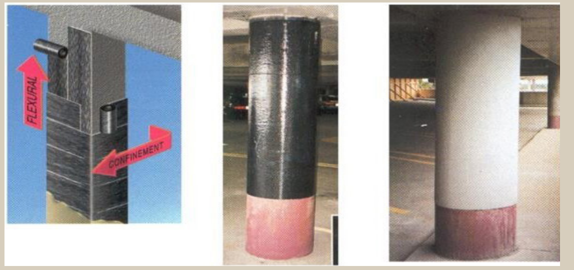

Fig. 23: Examples of fiber wrap system

High tensile carbon sheets can also be used as laminates. These laminates exhibits higher tensile strength compared to fiber wrap. The laminates are provided as discrete strips in the orientation of desired strength viz. shear or flexure, see Fig. 25 for illustration.

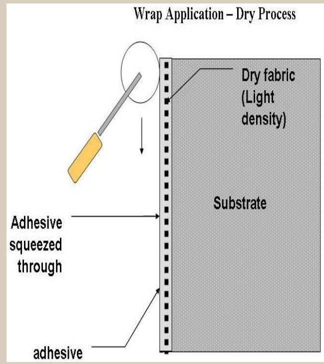

Fig. 24: Application of fiber wrap

Fig. 25: Carbon laminate

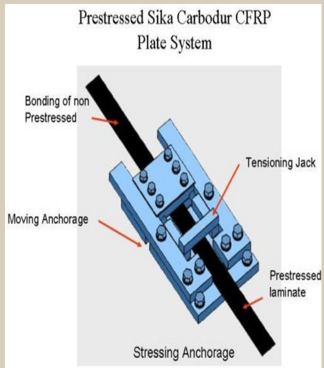

Fig. 26: Prestressed laminate

These laminates can also be prestessed as shown in Fig. 26.

CONCLUSION

Method of seismic strengthening of bridges is a case specific matter. Depending upon the requirements of a particular location, the system of strengthening of superstructure, substructure and/or foundations has to be decided. An attempt should be made to reduce seismic demand by providing seismic isolators/dampers or increasing flexibility of the structure, provided they do not impare efficiency and functionality of the bridge. Confinement of core of piers using concrete jacket or steel jacket is an effective method of strength enhancement. When reinforcement has to be added, reinforcement couplers and rebar fasteners turn out to be useful items of structure. All the bridge components need to be investigated for strength enhancement.