Strength Enhancement of Existing Multi-Span Bridges: A Literature Review

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***Abstract*—Retrofitting of existing structures is a very important point of consideration when it comes to existing structures. Hence, to improve the strength of a multi-span bridge when it is damaged by various aspects of deterioration, retrofitting is needed, to avoid any further damage or collapse. It is a very difficult task to finalize a suitable method for retrofitting of a structure. Considerable research has been done on the different conditions of bridges and buildings to identify the cause of damage and a suitable solution is provided in every case to provide a long life-span to the bridge along with enhanced strength and capability of bearing heavy loads. This paper aims to bring out the summarized findings of various literatures available on retrofitting of bridges.**

***Index Terms*—Bridge, Fibre Reinforced Polymer, pushover analysis, retrofitting, steel jacketing, strength enhancement.**

I. INTRODUCTION

Bridges play an important role in connecting roads, transportation, people and goods. They help us cross a barrier without closing the way underneath, may it be a river, a railroad track, a canyon etc. Nowadays, as countries are developing and due to immense growth in technology and construction techniques, new designs and methods are being developed and used for construction. However, these technologies are mostly used for building a new structure. What about the issues of the existing ones? Hence, to improve the serviceability and performance of existing structures, retrofitting of structures is carried out by using different methods and techniques as needed. Retrofitting is meant by adding something that a structure did not have already when it was manufactured. Some of the methods of retrofitting are-

1. Epoxy injection method
2. Fibre Reinforced Polymer (FRP)
3. Jacketing method
4. External plate bonding
5. Mass reduction technique
6. Adding new shear wall
7. Wall thickening technique
8. Adding steel bracing
9. Section enlarging technique
10. Base isolation technique.

Fig. 1- Beam jacketing

Fig. 2- Column jacketing

II. RETROFITTING

A process of modification of existing structures to make them more resistant to seismic activity and other calamities is known as Retrofitting. It includes all the structures like buildings, bridges, monuments, etc. However, it is not the only reason, it can also be done to improve the strength of a structure if it is damaged and improve its overall performance by using a suitable method and improving its bearing capacity and strength. One of the main advantages of retrofitting is that the traffic flow in many cases is not disturbed during the process, which reduces inconvenience of traffic.

The main advantage of retrofitting is that it improves the structural performance of any structure along with structural longevity. Other key advantages of retrofitting are as follows-

- Cost efficient.
- Avoids reconstruction.
- Low maintenance costs.
- Improved life-span of the structure.
- Can make structure seismic resistant after construction.
- Can make existing buildings green.
- Reduces the chances of collapsing.

III. LITERATURE REVIEW

A. S. Arya et. al. (1992) investigated the reasons of seismic damage to a bridge in Cachar district of Assam, India which was damaged during an earthquake of M=5.6 on Richter Scale in 1984. The design considerations were evaluated and found to be unfit for seismic resistance even according to IS 1983. The bridge bearings were shifted from its original location, which caused displacement of superstructure horizontally and laterally. Some piers were cracked and tilted. Also, spalling of concrete was observed. Hence, the bridge was analysed and two different methods of retrofitting were suggested which were seismic coefficient method and response spectrum method. Also, epoxy grouting was suggested for concrete elements adequately after re-analysis. All old existing bridges were recommended to be analysed and retrofitted before severe damage due to hazards [1].

Kazuhiko Kawashima (2000) This paper presented how the design philosophies and codes were affected by the Loma Prieta, Northridge and Hyogo-ken nanbu earthquakes in 1989, 1994 and 1995 respectively in New Zealand, Japan, EC and USA. The study emphasized Japan’s experience in the 1995 Hyogo-ken earthquake and hence described the Near Field Ground Motions developed during the earthquakes. Since there are limitations to apply the empirical green’s function method, a new hybrid simulation method for evaluation was developed and successfully applied for prediction in the 1995 Hyoko-gen earthquake in Kobe [2].

The design specifications of bridges were revised in 1996 [JRA 1996] and upgraded to the “Ductility design method” which applied to all the components predominating seismic factor and effects. The design of foundation consisted of Push-over analysis and the linear/non-linear response analyses and the liquefaction-induced lateral ground movement treatment are also described. The comparison among the codes of design is done. The description of the seismic retrofitting of 29,400 RC columns and piers by steel jacketing was conducted along with an increase in flexural strength in Japan. However, many problems were left unsolved for other effects [2].

Akihiro Kunisue et. al. (2000) experimented and tested the method of installing elasto- plastic steel dampers in existing reinforced concrete buildings using an analytical model with the aim to provide better seismic resistance to the buildings than conventional retrofitting methods. The main aim of this study was to test these dampers and hence, it was confirmed that this new method of retrofitting was effective in reducing seismic response and increase earthquake resistance in structures [3].

M. Dicleli and M. Y. Mansour (2003) studied the retrofitting of seismically vulnerable bridges in the State of Illinois and tested the economical and structural benefits of the same using Friction Pendulum Bearings (FPB). The Illinois Department of Transportation (IDOT) selected a bridge for a typical representation of seismically vulnerable bridges and a 3D structural model of the same was built and analyzed using the SAP2000 program. It was observed that the FPB helped in eliminating the use for retrofitting of the substructure of the bridge and the cost using FPB was found to be comparatively lesser than cost of retrofitting using any other conventional method taken into consideration. It was found that FPB may be used in regions of low to moderate risk of seismic activities for retrofitting of bridges [4].

Bassem Andrawes and Reginald Desroches (2004) evaluates three different technologies restricting the displacement of bearings in bridges during earthquakes. A simplified two degree of freedom analytical model, including two identical masses was considered and developed in MATLAB. The three retrofit devices considered in the analysis were the steel restrainers, the metallic dampers and the superelastic dampers (Shape Memory Alloys). A comparison between these three methods was done to restrict the relative moment of the hinge openings.

Using a suite of 8-strong ground motion records, the performance of the bridge model using the mentioned three methods was evaluated. The main objective of this analysis was to compare and obtain the most effective technology using smart material which was concluded to be the superelastic Shape Memory Alloy restrainers effective than the other two devices in reducing the hinge displacements in ground motion records. Also, it was seen that the lateral drift of the bridge was barely affected by the retrofit device used at intermediate hinges [5].

Fatih Altun (2004) experimentally determined the mechanical properties of RC jacketed beams and RC beams after loading. The main objective of the study was to determine and compare nine RC beams after its moist curing, whether they can withstand bending moment and their behaviours under simple bending and ultimate loading in both cases i.e., jacketed and ordinary beams, being under-reinforced. The ultimate load causing the failure of jacketed beam was measured to be more than the computed one. The experiments were performed in certified testing machines and it can be concluded that both the beams showed similar behaviour under loading and bending moments [6].

Sang-Woo LEE et. al. (2004) developed a method based on seismic damage risk and failure cost analysis for seismic retrofitting of bridges. A procedure for simulation is developed by using a simplified model of bridge which included various vulnerable components of a bridge and the actual seismic behaviour of girder-type bridges. After studying a lot of methodologies, it was proposed to find more productive measures for seismic retrofits.

Four model girder bridges are considered for evaluation which were 3 and 6 span precast prestressed bridges. The damage index and ranking indices of bridges are estimated and at last the seismic retrofit priority of bridges were determined from the ranking index. It was concluded that the developed methodology is more appropriate for determining the effects of analysis and also in evaluating the priority of existing and retrofitted bridges [7].

G. Furlanetto et. al. (2008) discussed two alternative approaches for the seismic retrofitting of bridges as in the past years in Italy, rehabilitation and retrofitting of bridges gained a continuous importance for especially new safety requirements issued by Italian codes. The key objective of the new design was stability of structure in post-elastic range. The paper presents some cases of retrofitted bridges by using these two methods: the first approach is concentrated for the upgradation of the structural performance during seismic activities while the second one is aimed at safeguarding the existing bridge by using a seismic protective system or base isolation. After designing the new structural elements, an evaluation of the widened and retrofitted bridge is carried out by push-over analysis to verify the suitability of the old bridge element [8].

Zahra Riahi and Farzad Faridafshin (2008) explains about the details and characteristics of Fibre Reinforced Polymer (FRP) method of retrofitting with seismic retrofit of RC bridges. Other applications of FRP along with its effects after retrofitting are addressed. The main aim of the study is to check the durability and mechanical characteristics of FRP in accordance with the requirements of the condition of bridge and its strength during seismic activity.

It has been examined whether the characteristics of FRP wraps are able to withstand the seismic events and its merits and demerits over other conventional methods of retrofitting. In case of severe damage, the FRP wraps may be used with Epoxy injection method to regain the capacity to a greater extent. As a result, FRP wrapping would be a lot more effective in highly seismic regions than in moderate zones. However, this topic is not studied in detail and requires further research in this area whereas the long-term performance of FRP should also be investigated [9].

Y. C. Sung et. al. (2009) an easy assessment method is introduced for state-of-the-art pushover analysis using SAP 2000 software for first stage of evaluation for which 2213 bridges were considered. For the second stage, 140 of those bridges were considered for the seismic assessment of bridges by ATC-40 method in the detailed analysis. The method of steel jacketing of 9 mm thickness was chosen for the retrofitting. The main aim of the study was to imcrease the life span of the bridge by analysis and carrying out the suitable retrofit approach, which was successfully achieved by the selected technique. The bridge is now estimated to service for another 100 years by using an economical approach [10].

F. Paolacci et. al. (2012) aimed at studying the behaviour of an old R.C. viaduct with two piers under seismic loading for testing analytically and experimentally by PsD test. The modelling of the structure was done using the non-linear code OpenSees numerically, with the non-linear behaviour of each piers due to strain penetration, shear and bending effects. In the numerical model, the vertical displacements were restrained whereas, the rotational displacements were permitted. A simulation model helped a lot in the seismic assessment of the bridge [11].

T. A. Majid and A. Yousefi (2012) presented a study of Multi Criteria Decision Making (MCDM) method to rank the bridges for retrofitting and seismic resistance. The criteria included various factors such as seismic hazard, vulnerability and importance of the bridge etc. which was however still difficult in determining the priority of bridges and ranking them. Hence, of all the MCDM methods, the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) technique.

This was introduced in 1981 by Yoon and Hwang which focused on the idea that the alternative to be selected should be as far from negative solution as it is close from the positive solution. It was concluded that the TOPSIS model was the most efficient and considerable for the prioritization of retrofitting of bridges in MCDM method. This is the most useful and effective when the Decision Maker (DM) is not able to decide the preferences by giving the proper clarity of ideas in its results. A prioritization method may be developed using these results [12].

Komal Bedi (2013) studied and described various methods of retrofitting of concrete members, members as a structural body, retrofitting of foundation, repairing of cracks, historical buildings and monuments, innovative technologies for historical preservation, seismic retrofitting techniques, member-level retrofitting, surfaces treatments and some recent retrofitting techniques as well [13].

Sotiria P. Stefanidou and Andreas J. Kappos (2014) developed a component-based methodology by examining the effect of retrofitting of bridge using various methods in terms of fragility curves. The main objective of this paper was to carry out the retrofitting process on a bridge and then quantify the results as probabilistic seismic vulnerability curves. The retrofitting of piers, abutments and bearing was done by using different methods like R/C jackets, FRP jacket and upgradation of the bearings as Lead Rubber bearings or elastometric bearings with higher dampers were carried out respectively.

The bridge was structurally modelled using OpenSees for different performance objectives to be obtained. The derived methodology was followed and used for the derivation of fragility curves of the retrofitted bridge. The important finding was that the different solutions used together proved to be effective and increased the performance of the bridge, which helped to evaluate these retrofit techniques individually. It was stated that the developed methodology will be extended to different structural designs of bridges and will be combined with the optimum retrofit measure [14].

Ranjith Dissanayake and Chaminda S. Bandara (2016) studied the case of a wrought iron railway bridge in Sri Lanka and emphasized retrofitting to be a better option rather than demolishing the bridge. By considering the two important criteria i.e. the damage caused due to fatigue by vehicle loading and by other unknown actions, a condition survey followed by the material testing and analysis using a Finite Element Model was done. The bridge modelling was done by SAP 2000 software, as a 3D frame element model. They validated the model by a field test consisting of a locomotive with six numbers of 13.16-ton axles for five different loading cases in order to measure the strain, displacement and acceleration at the critical areas and parts of the bridge. The checking of bridge was done for higher loading as well and after the analysis of verification test results, it was concluded that the retrofitting work was successful with a fatigue life of bridge being 30 more years and was more sustainable rather than constructing a new bridge [15].

Vikash Kumar Dwivedi and R. C. Singh (2017) studied different articles and concluded that retrofitting is the most important thing for an existing bridge damaged due to static or dynamic loading or seismic activities. They noticed that a structural is generally damaged by seismic forces but their study was for the Chhattisgarh area in India, where it is not a seismic prone zone. Hence, it was concluded that there is no need of retrofitting of structures in this area as there are very low chances of damage and hence they do not require seismic resistance and require just the routine maintenance for the bridges which are damaged or deteriorated due to static and dynamic loading [16].

Jure Radnic' et. al. (2018) presented the basic characteristics of the three bridges, which are as valuable architectural heritage. The bridges developed very wide longitudinal cracks which were basically due to the load transferred by the sprandel walls. This was due to heavy traffic flow on the bridges as the bridges were very old, they had low bearing capacity and hence were on the verge of collapsing. The effects of ageing and deterioration of the drainage system was also observed as they were built in the late 19th and early 20th century. The embankment above the arches was replaced with concrete and other aspects were restored as almost the original ones on basis of appearance and functionality but were enhanced successfully by strength and load carrying capacity of the bridges along with seismic resistance [17].

V. C. Patil and Nikhil V. Pawar (2018) studied the needs of seismic retrofitting of bridges and its importance. The reasons for damage in structures after seismic activity were found out and different types of damages and their details were specified along with the modelling of a sample bridge model in STAAD PRO software. After retrofitting, re-analysis according to latest seismic design considerations were done. It was observed that after the recommended design steps and retrofitting, the structure could withstand earthquakes with minimal damages which can be repaired. Hence, repairing and retrofitting for old bridges was recommended [18].

K. G. Vijay and T. Sahoo (2018) studied the mitigation of the waves induced by hydrodynamic loads on a couple of retrofitted bridges by using external porous plates. The main aim of the work was to study the various hydrodynamic characteristics by analysing the wave forces on the retrofitted structures and the floating bridge components after which it was seen that the horizontal forces on the bridge were reduced while the vertical forces were increased in certain situations.

Hence, an analysis was carried out on Multi Domain boundary element method (MBEM) in which the efficiency of numerical model was validated with the results obtained through literature. As a result, it can be said that for a structure to have a long service life, selection of physical parameters should be considered of great importance than any other parameters in the design of new structures along with the wave conditions of the bridge site [19].

A. K. Shukla and P. R. Maiti (2019) studied the strengthening of the footbridge over Yamuna River in Delhi by rehabilitation and retrofitting techniques. The bridge was deteriorated due to over loading, salinity of water and its age factor etc. The method of steel jacketing was adopted for the cantilever beam portion which was designed and modelled using STAAD Pro V8i software and the slab of footway was scrapped completely due to unserviceability of the bridge as it was damaged and could not be used further. After jacketing, 1 mm thick pre-painted galvanised iron (PPGI) sheets were used for the permanent shuttering of the deck slab and new deck slab was laid. As a result of analysis, the bridge was found safe to use [20].

Rohit J. Desai and Pandurang S. Patil (2020) analysed the reasons of failure of the bridge which was hit by floods in 2019 in the Western Maharashtra part of India. The bridge model was analysed using STAAD Pro and it was concluded that it was in its permissible limits. As a result, it is emphasized that proper inspection and maintenance to continuously check the functionality of bridges is necessary to save structures from such disasters along with advance design methods [21].

IV. SUMMARY

This paper gives an overview on strength enhancement of existing multi-span bridges. After studying various literatures on retrofitting of structures, it can be summarised that the observed damages caused to the bridges are due to various reasons which cannot be specified as of now. However, some possible reasons may be due to:

1 Overloading of the bridge.
2 Constant humidity and temperature variations
3 Ageing of the bridge.
4 Low grade of concrete used.
5 Seismic damage.

All the same it can be summarized that, many of the bridges in consideration of the studies were typically damaged due to seismic activity or due to some natural hazard. This happened mainly due to the lack of seismic design considerations in the design of the bridges. This was because the bridges were constructed back in the late 19th or early 20th century, when the design considerations of seismic activities were not included.

Some methods which are commonly used are external steel plate bonding, FRP wrapping, epoxy injection etc. which are one of the best techniques available in the current situation. Further detailed study to find out the suitable methods to be adopted in the required situation is needed. The main aim of this study is to find the causes of deterioration of structures along with the suitable solutions adopted for strengthening of the same.

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