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Comparitive Study on Integral and Conventional Bridges Subjected to Flood Loadings

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Abstract—Bridges are traditionally built with expansion joints at the ends to allow for longitudinal displacements of the superstructure due to temperature variations. Thus, most conventional bridges possess expansion joints and bearings, which are expensive in their materials and installation. Elimination of expansion joints in bridges may reduce the construction costs, overcome many of the maintenance problems, and increase the stability and durability of the bridges. These economic and functional advantages are generally recognized by bridge Engineers leading to the concept of integral construction or integral bridge. The lack of expansion joints in integral bridges results in reduced repair and maintenance costs throughout the service life of the bridge. It improves seismic resistance and extends long-term serviceability. The need to design bridges to withstand flood and debris loads has long been recognised however bridges are still failing to live their entire design life when subjected to extreme flooding events. This project presents a structural evaluation of bridges when subjected to the flood loadings that took place in Kerala , 2018. For this study, an existing conventional bridge is selected and flood analysis is carried out using SAP 2000. For the same site conditions, an integral bridge with equivalent cross section is analyzed, and results are compared.

Index Terms— Bearings, Conventional bridges, Expansion Joints, Flood loadings, Integral bridges, Kerala Flood, SAP 2000

1 INTRODUCTION

THE bridges are traditionally built with expansion joints at the ends to allow for longitudinal displacements of the superstructure due to temperature variations. Thus, most conventional bridges possess expansion joints and bearings, which are expensive in their materials and installation. Elimination of expansion joints in bridges may reduce the construction costs, overcome many of the maintenance problems, and increase the stability and durability of the bridges Theseeconomic and functional advantages leads to the concept of integral construction or integralbridge. The lack of expansion joints in integral bridges results in reduced repairand maintenance costs throughout the service life of the bridge. In addition, when usedas part of highways, integral bridges enhance the comfort of travelers dueto lack of expansion joints and provide better lateral rigidity. Moreover, modern integral bridges areknown to have performed well in recent earthquakes due to their monolithic construction. One of the most common problems in the seismic resistance of traditional Bridge construction is unseating of the superstructure from the support bearings. This problem is eliminated in integral abutment construction as there are no support bearings. However, the system of joints and bearings used in traditional construction allows superstructure movements during a seismic event which result in a decreased demand on the foundation. In integral abutment construction, the foundation piles and abutment must be able to accommodate these increased demands.

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There has been a general agreement that integral abutment construction provides increased seismic resistance with respect to traditional construction through increased redundancy and continuity. However, detailed analysis of the earthquake resistance of this type of construction has not been conducted.

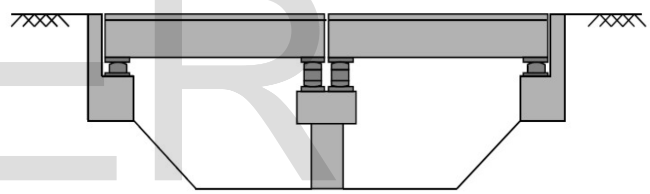

Figure 1 Conventional Construction

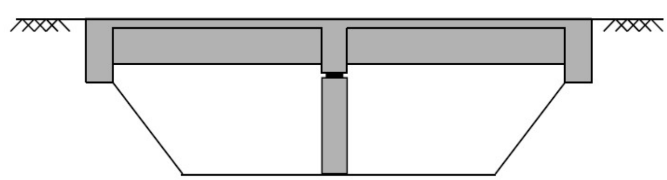

Figure 2 Integral Construction

The simple characteristics of integral Bridges make for rapid and economical construction. For example, there is no need to construct cofferdams, excavation of footing is made, backfill is placed, cofferdams is removed, Bridge seats are prepared, bearings are placed, back walls, and deck joints. Instead, integral construction generally results in just four concrete is placement days. After the embankments, piles, and pile caps have been placed and deck strings are erected, deck slabs, continuity connections, and approach slabs are followed in rapid succession. In extreme cases, some multiple span integral Bridges are been completed with just two concrete placement days; one for the structure itself, and one for the approach slabs.Integral Bridges can be built without bearings and deck joints. This will not only save initial costs but also reduce maintenance efforts. This is an important benefit because presently available deck joint sealing devices have such short effective service lives.

The most obvious reason why integral Bridges have become so popular, especially with transportation departments located on above the Snow Belt, is their outstanding resistance to deicing chemical corrosion and deterioration. Since these Bridges do not have movable deck joints at abutments and piers, deck drainage contaminated by deicing chemicals cannot penetrate Bridge deck slabs and adversely affect the primary Bridge members.

While using multiple span integral Bridges to replace single span structures with wall type abutments, the great adoptability of integral Bridges allows them to span across existing foundations, thus avoiding the need to remove them. Since small Bridges are usually replaced in 50-years cycles, use of integral Bridges with their simple pile foundations will considerably simplify future Bridge replacements. Also, the more durable integral Bridges help to increase the serviceable Bridge age and extend replacement by two or more decades. Like most of the jointed Bridge counterparts, integral Bridges are subjected to secondary effects due to shrinkage, creep, thermal gradient, differential settlements and differential deflections.One of the most important attributes of integral Bridges is their reserve strength capacity. The integrity of their unified structural system makes integral Bridge extremely resistant to the potentially damaging effects of illegal super loads, pressures generated by their strained growth of jointed rigid pavements, earthquakes, and debris laden flood flows.

2 LITERATURE REVIEW

Wilson J.C. (1988) conducted a research study to assess the effects of the stiffness of monolithic bridge abutments on the seismic performance of IBs. In this study, a simple analytical model was developed that describes the stiffness of the abutments with six equivalent discrete springs for three translational and three rotational degrees of freedom. These springs are assigned various stiffnesses to include the effects of the abutment wall, pile foundations and soil. However, inertial effects arising from acceleration of the abutment and backfill mass during the excitations caused by an earthquake was not considered in this model.

Murat Dicleli (1998) conducted a study on rational design approach for prestressed-concrete-girder integral Bridges.An analysis procedure and simplified analytical models are proposed for the design of integral bridges.The earth pressure forces acting on integral bridge abutments are formulated in correlation with the effects of temperature variation. Some important design considerations for various integral bridge components are also highlighted. The benefits of using the proposed analysis method for the design of integral bridges are discussed. It was concluded that it may be possible to obtain more sound and economical designs for integral bridges using the proposed design method.

Spyrakos and Loannidis (2003) have conducted a research study on the seismic behaviour of IBs. In this study, the effect of soil structure interaction on the seismic performance of IBs was evaluated. The analytical model was also validated with field measurement. However, the nonlinear effects of soil-structure interaction were neglected and a single direct analysis technique that models the whole system including the superstructure, substructure and soil was not used due to its complexity.

Shatirah Akib,M. M. Fayyadh,S. M. Shirazi, Budhi Primasari and M. F. Idris (2003) have conducted a research study on Innovative countermeasure for integral bridge scour .Advantages of integral bridges include reduction of initial construction and maintenance cost. Scour was the main problem which caused the bridges to fail and collapse during heavy rain and flooding. Most of the previous studies focused on the scouring impact on conventional and traditional bridge. Very few studies investigated on scouring effects on integral bridge and its countermeasure. This paper highlighted the innovative countermeasure to prevent the impacts and consequences of scouring on integral bridge.

Robert J. Frosch, Michael E. Kreger, Aaron M. Talbott (2009), conducted a study to evaluate the response of integral abutment bridges to seismic loading. For this, field investigation, analytical investigation and laboratory investigation were conducted.Results of the field, analytical, and laboratory investigations were used to evaluate allowable bridge lengths based on seismic performance. Finally, design recommendations are provided to enhance the seismic performance of integral abutment bridges.

Ahmad M. Itani and Gokhan Pekcan (2011) investigated about seismic performance of steel plate girder bridges with integral abutments. Analytical investigations were conducted on computational models of steel bridges with integral abutments to determine their seismic behaviour as a system and to develop seismic design guidelines. Based on the analytical investigations and available experimental research, guidelines for the seismic analysis and design of integral abutment bridges were developed.

Aslam Amirahmada and A. Rahman Al-Sinaidi (2013) conducted a study to analyse Integral Bridges by Finite Element Method.As temperatures change daily and seasonally, the spans of integral bridges increase and decrease, pushing the abutment against the approach fill and pulling it away. In this study, a finite element analysis has been performed to gain insight into the interactions between integral abutments, approach fills, foundation piles and foundation soils. The finite element analyses indicate appreciable rotations occur in integral abutments, resulting in the shear and moment reductions in the piles.

Shaikh Tausif A and L.G KalurkarÅ (2014) investigated about the behavior of Integral Abutment Bridge by Different End Conditions. In this paper total four models are compared two with considering soil interaction and other without soil interaction and live load is applied using MIDAS CIVIL. The paper motive is to study the trends in bending moment, shear force and deflection in central and end girders and deck slab due to dead load, live load with combination of thermal loads. In case of IAB WSA (Integral Abutment Bridge With Spring Analysis) the stresses is more as compare to SSB and less as compare to IAB because at ends abutments a spring force is develop.

Mr. Kiranakumar V Arutagi, Prof. Ravichandra Honnalli (2017) a comparative study is carried out on a typical integral

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bridge and a conventional simply supported RC girder bridge of same geometry and loading conditions. For modeling of bridges, 60 m length was considered. It was divided into 3 spans of 20 m each. The bridges were modelled and analyzed in SAP 2000. The seismic analysis was carried out by response spectrum method of analysis and the seismic responses of integral bridges were compared with the responses of conventional RC girder bridge. From the study it may be concluded that, integral bridges performs better than the conventional RC girder bridge under seismic loadings and also integral bridges requires minimum cross-sectional area as compared to conventional bridges.

Ioannis Tegos, Anastasios Sextos, (2012), conducted a study about the role played by the abutment when it is monolithically connected to the deck and its potential implications on the bridge integrity, regularity and complexity. They found that the the implementation of rigidly supported abutments on integral bridges is a possible and promising solution for the reduction of the seismic displacements of particular bridges. Investigation, concerning real bridge systems, in order to study the complex interaction between the main parameters of the problem is not considered.

M. Naji, A. R. Khalim, (2014), developed a soil model for Soil Structure Interaction in Time History Analysis. Nonlinear time history analysis on two-dimensional integral abutment bridges under seismic loads were performed with finite element software. Based on the time history analyses results, hard clay surrounding the pile increases pile head force, pile head moment and girder axial force that is a critical point in bridge design.When seismic load is applied on an integral abutment bridge in a longitudinal direction, maximum pile deflection and maximum abutment displacement happen at the pile head. Maximum moment happens in the head pile. The pile head moment will decrease when the backfill is compacted and increase when the piles are located in stiff clay. So, this moment is maximum for the case with piles in hard clay and loose sand backfill, and minimum for the case with piles in medium clay and dense sand backfill. Dense sand in backfill behind the abutment wall is usually recommended, since it reduces the pile deflection, the abutment wall displacement, the girder axial force, and particularly, the pile moment.

Yu Bao and Andrew Rietz,(2013),studied about seismic soil-structure interaction in fully integral abutment bridges with HP steel piles. In this, the seismic soil-structure interaction mechanisms are investigated for the bridge longitudinal direction as well as for the bridge transverse direction. Both simple span and two-span bridges are analyzed using the finite element program ANSYS. Investigation of seismic load distribution shows that the piles take a larger portion of the load in the bridge transverse direction, whereas the soil takes a higher portion of the load in the bridge longitudinal direction.

Aparna Prasad and Jiji Thomas (2016) conducted a Comparative Study on Fatigue behaviour of Integral and Conventional bridges. Fatigue evaluation of integral bridges is studied by using deflection characteristics and based on S-N curve. The action of repeated action of moving loads on bridges has significant effect on the life of the bridge. From the fatigue analysis, it has been seen that for the integral bridge, life is 118 years. For the conventional bridge it is about 83 years. Total deformation and damage of conventional bridge is much greater than integral bridge. Partial safety factor for integral bridge is more. Due to the increased stiffness of integral bridge, it shows lower deflections. From the fatigue analysis it can be seen that integral bridges have promising solution for better fatigue behavior with maximum life than that of conventional bridge.

3 DESCRIPTION OF STUDY AREA

Chalakudy River is the fifth longest river in Kerala. The Chalakudy river is formed by the confluence of five streams, Parambikulam, Kuriarkutty, Sholayar, Karappara andAnakkayam, all of them originating in the Anamalai Hills of the Western Ghats. Out of these,Parambikulam and Sholayar rivers originate from the Coimbatore district of Tamil Nadu.Karappara and Kuriarkutty rivers originate from the Palakkad district in Kerala. At about470m above M.S.L. the Parambikulam joins the Kuriarkutty river. Further 9 km down, theriver is joined by the Sholayar. The Karappara joins the main river at about 455m aboveM.S.L. The Anakkayam joins the main river 8 km further down at 365m above M.S.L. In theinitial course, the river passes through thick forests and its flow is broken by many falls till itreaches the plains at Athirapally.The Chalakudy river basin is bounded by the Karuvannur sub-basin on the north and thePeriyar sub-basin on the south. The basin consists of about 30,000 ha of wet lands. The basinreceives and average rainfall of about 3000 mm. The total drainage area of the river is 1704sq.km and out of this 1404 sq.km lies in Kerala and the rest 300 sq.km in Tamil Nadu. Thelength of the river is about 130 km. The estimated runoff has been compared with the discharge data of Arangaly G&D site ofCWC. The plot of flood hydrograph of Arangaly G&D site is given in Figure 3.

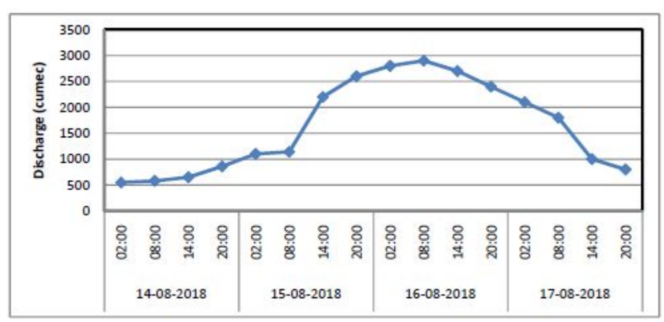

Figure3: Discharge data of Chalakudy river at Arangaly G&D site

The maximum discharge at Arangaly G&D site was about 2900 cumec on 16.08.2018 at 08:00 hours. The cumulative runoff for 15-17, August 2018, computed from the Arangaly G&D records is about 525 MCM, while the estimated runoff from IMD rainfall is about 508 MCM for a runoff coefficient of 0.9.

4 DESCRIPTION OF STRUCTURE

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The bridge is a five span RC bridge with span length 20.61m. The bridge deck is 9.3 m wide. It consists of 200 mm thick RC slab, supported on four 1.35 m deep RC precast I-girders at 2.3 m spacing. The diameter of piers is 1.5 m and they are connected at the top by 1.8 m wide & 0.8 m deep pier cap beam. Primary elements of bridge are modeled in CSI SAP2000 version 14. Finite element meshing procedure is also assigned for the bridge superstructure. Geometric details of bridge is shown in Table 1 and cross section details is shown in figure 4

DESCRIPTION	DIMENSIONS
Grade of concrete	M40
Reinforcement	Fe415
Length	103.3m
Span	20.61m
Width of bridge deck	9.3m
No. of span	5
Expansion gap	50mm
Thickness of deck slab	200mm
Diameter of Pier	1.5m
Size of Pier cap	1.8m x 0.8m

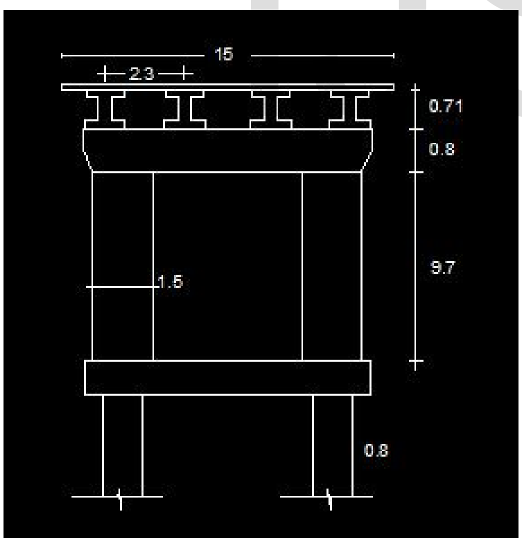

Figure 4Cross section details of bridge

5 MODELLING

5.1 CONVENTIONAL BRIDGE

For modelling of conventional bridge, five bridge spans eachhaving 20.61m length and separated by means of expansion joints of 50mm are selected. Bearings are also provided between the superstructure and piers. The size of the Neoprene pad bearing used is 350 mm×450 mm and 61 mm thick bearings.Fig 5 shows the model of conventional bridge.

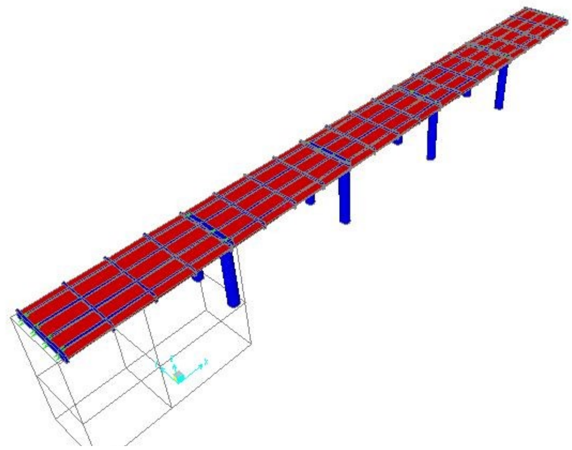

Fig 5 : Model of Conventional bridge

5.2 INTEGRAL BRIDGE

Integral bridges act as a rigid structure. It minimizes the use of bearings and resists large lateral forces. So for the modelling of integral bridge joints and bearings are eliminated. Integral bridge are modelled with boundary conditions set to restrain movements in vertical direction and accommodate the movements in horizontal direction. Figure 6 shows the model of integral bridge.

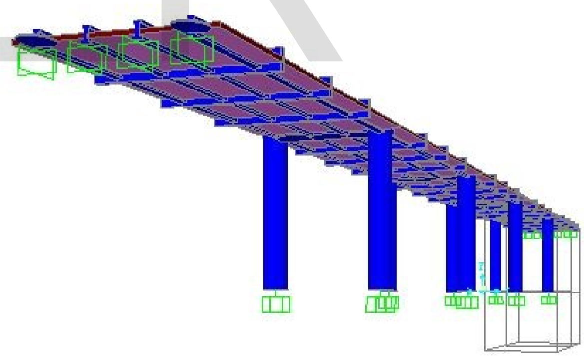

Figure 6 : Model of Integral Bridge

6 LOAD CASES

There are no load factors that increase or decrease any of the load cases, therefore the load combination will simply be the sum of the ultimate flood loads.

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Table 2 : Load cases and load combination

LOAD CASE	CONTRIBUTING FORCE
1	Self-weight
2	Drag forces (piers)
3	Lift forces (piers)
4	Buoyancy (full submergence)
5	Hydrostatic thrust

7 FLOOD LOAD VALUES

The forces are calculated according to Indian Standard Specifications and Code of Practice for Road Bridges, Section two.

FORCE TYPE	FORCE VALUE	FORCE DIRECTION	BRIDGE COMPONENT THE FORCES ACT ON
Drag force	103.304 KN	Negative Y-direction	Piers
Lift force	59.651 KN	Positive X	Piers
Buoyancy	131.3755 KN	Positive Z-direction	Piercap
Buoyancy	120.69 KN	Positive Z-direction	Girders
Buoyancy	1976.10 KN	Positive Z-direction	Deck
Hydrostatic thrust	197.61 KN	Negative Z	Deck
Hydrostatic thrust	94.34 KN	positive Y	Girders
Hydrostatic thrust	18.505 KN	Positive X	Piercap
Hydrostatic thrust	1470.80 KN	positive X	Piers

8 RESULTS AND DISCUSSIONS

This includes the analytical results of the integral bridges under flood loadings. These results were discussed with comparison of conventional bridge results. The displacements and modal information are obtained in the analysis. Table 4 shows the displacement result and table 5 shows the modal information.Fig 7 shows variation in displacement in both bidges.

Table 4 Displacement Results

Span	Displacement of deck in Conventional bridge (mm)	Displacement of deck in Integral Bridge (mm)
Span 1	22.486	29.384
Span 2	119.89	53.94
Span 3	120.72	53.85
Span 4	86.1562	29.09

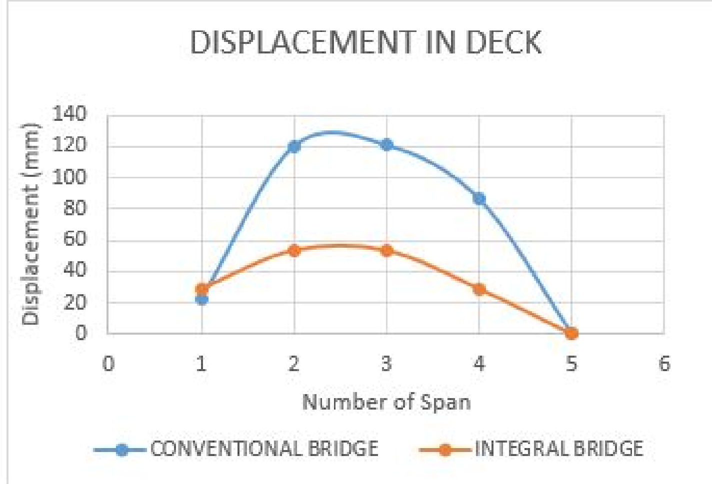

Fig 7 Graph showing variation in displacement in both bridges

Table 5 Modal information of integral bridge and conventional bridge

	CONVENTIONAL BRIDGE		INTEGRAL BRIDGE	
Mode	PERIOD (sec)	FREQUENCY (cyc/sec)	PERIOD (sec)	FREQUENCY (cyc/sec)
1	0.651	1.535	0.318	3.141

Maximum displacement obtained for conventional bridge is 120.72 mm and for integral bridge it is 53.94mm. It is found that integral bridge has smaller deflection when compared to conventional bridges due to its rigid nature. This is due to the presence of continuous deck slab and monolithic connection between deck slab and girders in the integral bridges.

Structures with higher natural frequencies and a short natural period, tend to suffer higher accelarations but smaller displacement. In the case of structures with lower natural frequencies and long natural period, the structure will experience lower accelarations but larger displacement. From Table, it has been observed that for integral bridge, the maximum period of vibration is 0.318 seconds with a frequency of 3.141 Cycles per second. The maximum period of vibration of conventional bridge is noted as 0.651 seconds with a frequency of 1.535 Cycles per second.

9 CONCLUSIONS

In this study, displacement and modal information are obtained and compared. From the modal analysis, it has been seen that for integral bridge, the maximum period of vibration is 0.318 seconds with a frequency of 3.141 Cycles per second. The maximum period of vibration of conventional bridge is noted as 0.651 seconds with a frequency of 1.535 Cycles per second. Therefore it is found that larger displacement occurs in conventional bridge as compared to integral bridge.

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