International Journal of Engineering & Technology, 7 (3.6) (2018) 59-63

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Extension of Existing Platform of Kochi Metro to Accommodate More Train-Cars

M. Akul Nair[1*], A. Sofi[2], V. Kannan[3]

[1]*M.Tech Structural Engineering, Department Of Structural & Geotechnical Engineering, SCALE,VIT Vellore, Tamil Nadu, India.*
[2]*Associate Professor, Department Of Structural & Geotechnical Engineering, SCALE, VIT Vellore, Tamil Nadu, India.*
[3]*Assistant Manager (Civil), Kochi Metro Rail Limited, Kochi, Kerala, India.*

Abstract

The metro rail being successfully a mode of transportation that is by far largely the main and the most used service for easier travelling is posed with restriction limited due to the existing design. Kochi metro being elevated throughout has provision of extension of platform to allow more passenger thereby more train cars. In this paper an attempt is made to provide easy, efficient and low cost method of extension of platform using steel plate girders as the main super structure component. The model is developed and analysed in SAP2000 which is then checked for deflection and reinforcement criterion. A 3D finite element model of the composite steel concrete girder is developed using ABAQUS to observe the load and stress transfer as well as the behaviour of shear studs.

Keywords--- *Metro, plate girder, shear studs, damper, FE model, passenger flow, pier.*

1. Introduction

Kochi Metro being the newest metro line was designed and constructed for a fast transportation between important hubs in Kochi city. The present metro provides transportation services between 16 stations starting from outskirts of city to right into the city center. Metro station is designed over a length of 87m with entry & exit through both the left and right side of the station. Metro train is assembled using 3 train cars with an overall length of 61m providing a crush carrying capacity of 600 persons at single journey with a headway between consecutive metro of 5-6 minute with no further possibility of extension of station as currently designed.

During peak hour traffic the passenger transportation gets slowed down due to only 600 persons can be transported at a time, even though headway decrement can be brought down to 1min only with an another possible alternative being extending the platform by addition of a platform through girder [1] addition which will in turn allow an addition of a coach or two. Girders being the one of the type of suitable or possible way of an extension [2]. The girders are designed such as to carry the oncoming load due to the passenger movement with the load transfer mechanism from the concrete deck to the steel plate girder using shear stud as the shear connector [6]. With various mode of connection available for concrete and steel such that structure performs homogeneously due to variable loads occurring in bridge superstructure [8]. The connections between the surfaces using different gusset plates being a less costly alternative has its disadvantage from preventing of slip between the concrete – steel surface [3].

Additional platform with a steel beam as the support for the oncoming deck with its structural application of moving vibratory loads and action of wind due to its elevation is to be provided a suitable damper [15]. The model is analysed for deflection, steel reinforcement and other stress and load related studies using SAP2000 [2] and finite element modelling for capturing intrinsic behaviour of the structure. Passenger study based on current travelling as well as the peak requirements at peak hour is estimated with pedestrian forecasting the flow pattern is seen to be increasing [20]. Need for easy commutation is required [4] to prevent rush at the station. The headway between consecutive metro trains is insufficient to cater to the peak hour rush.

The present paper contributes to proposing single addition of platform providing the possibility of addition of train cars and thereby more passenger transported. Modelling of the structure in software along with numerical investigations proved to validate the proposed means of extension. Metro system being the latest additional transportation mode especially for elevated structure throughout, has the advantage of extension as and how much required to control the rush at peak hours.

2. Procedure and Methodologies

Superstructure composition

Superstructure comprising of a set of plate girders 20m in span supported at three ends i.e at both the supporting end portions and at the middle span. Plate Girders with top and bottom flanges of 600mm wide and 50mm deep along with web of 2000mm deep and 15mm thickness are designed. The plate girders are placed at a spacing of 1.5m such as to support slabs on top of it. Girders are designed with web stiffeners comprising of 10 panels with a spacing of 2m c/c. The slabs are designed as one way slab comprising of 3 panels each of 7m wide and 3m deep with an overall depth of 140mm. Slab reinforcement designed with 10mm dia at 230mm c/c at top, 8mm dia at 180mm c/c at bottom and distributed steel of 8mm dia at 250mm c/c.

Design criterion & details

Extension of platform is done considering the basic parameters required to accommodate additional train cars. The existing composition of train cars is of two driving motor car at both the ends and a central train car which adds upto 67m length of entire train over metro station of 81m.

The criterion considered for extension of platform was based on the existing and future and passenger increment along with the headway are given in Table 1. The existing metro station spanned over 81m supported over piers spaced at 13.5m c/c with a concourse level of 7.5m and a mandatory clear cover of 5.5m from the road level as shown in Fig 1.

Table 1: Future Passenger Study

Year	Passenger/ Day	Headway (min)	PHPDT*	PHPDT Capacity Available
2015	381868	5	13681	7200
2020	468130	4	17663	9000
2025	539427	3	21065	12000
2030	600526	2	23621	17500

*PHPDT refers to Peak Hour Peak Direction Traffic

Structure components and its loading

Various components considered for the extension of platform are piers, plate girders and slabs with three piers for supporting an extension at 10m c/c.

Piers with extended pier cap forming a cantilever support are proposed which can be placed only at the road ends rather than the existing piers which are at the median of the road.

Loading onto the superstructure is based on the loading criteria adopted for crush carrying capacity which is about 6 persons per square meter with an average passenger weight of 65kg.

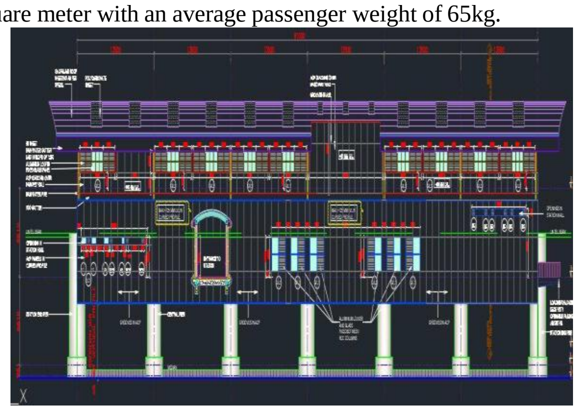


Fig. 1: Typical metro station

Plate girder and deck design parameters

Yield
Stress of steel, fy= 250 N/mm^2 Material
factor for steel= 1.15
Deal load factor = 1.35
Imposed load factor = 1.50
Grade of concrete & steel = M20 & Fe415

Plate girders are designed for a moment carrying capacity of the flanges of 13,370 kN/m with a basic shear strength of 112.13 N/mm^2. The panels are checked and designed to carry shear force such that the stiffeners provided are capable of having a bearing capacity of 2173.9 kN. The Deck slab designed as one way slab for maximum negative bending moment and maximum positive bending moment.

The slab on the girder are connected through shear studs which are designed of 13mm diameter over a height of 65mm with a spacing of 100mm c/c.

The typical arrangement of extended platform is as depicted in Fig 2.

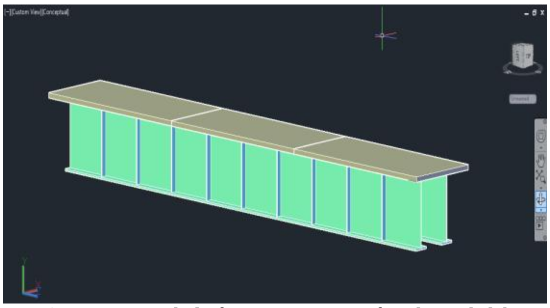


Fig. 2: Proposed platform comprising of girder and slab

Pier design

The pier is designed with extended pier cap for a length of 9m. Pier cap designed such as it has 1.3m depth at extreme end and a varying cantilever depth of 0.25m. The pier designed for a height of 12m above the ground level of 0.8m width over a footing spanned within 3.6m by 4.6m with a thickness of 0.6m. The pier is as depicted in Fig 3.

Safe Bearing Capacity = 35 t/m^2
Bottom of Deck = 12.00 m
Platform Level = 14.50 m
Width of Decking = 9.00 m
Height of Deck = 2.10 m Thickness of slab deck + tile = 0.15 m Top of RCC footing = 0.60 m
Elastomeric Bearing = 250mm x 250 mm x 250 mm

Pier designed considering a wind factor force of 0.042t on deck, 0.45t considering moving loads whereas maximum force were obtained at footing of about 7.429t. Foundation pressure so obtained was 22.41 t/m^2 without considering wind factor and a maximum pressure of 23.8 t/m^2 on account of wind force acting on pier. RCC footing was designed of 16mm diameter bars with an effective depth of 542cms. Provide 20mm diameter bars at 130mm c/c along longitudinal direction and 12mm diameter bar at 200mm c/c along transverse direction along with top nominal steel of 12mm diameter bar at 150mm c/c along both longitudinal and transverse direction.

3. Modelling and Analysis

The model is developed for analysis in SAP2000. Modelling of the structure were done considering steel plates of 15mm and 50mmm thickness which constitute to form the parts of the I girder such as the flanges and web of the I girder which is then replicated throughout the entire span of 20m. The plates for the web stiffener are of thickness 25mm placed at 2m c/c at entire span as depicted in Fig 3. The ends are simply supported. Loading conditions considered are of dead load, imposed load, wind load and earthquake load wherein imposed load is distributed throughout the span of the structure. Wind load and Earthquake load are the critical loads for elevated structure having utmost importance. Load coefficients are as depicted in Table 2.

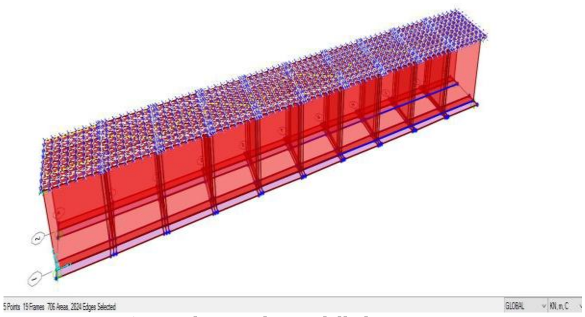


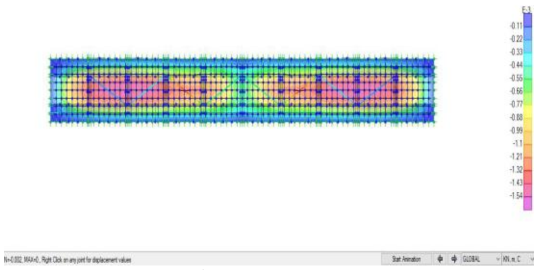
Fig. 3: Plate Girder modelled in SAP200

Table 2: Load Criteria

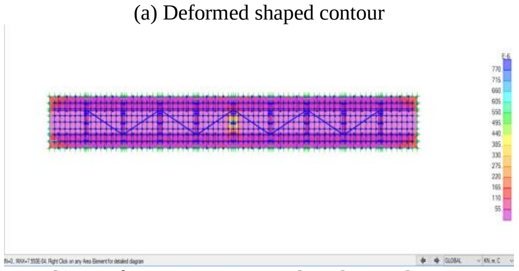
Wind Coefficients		Seismic Coefficients
Wind Speed, V_b	39m/s	Seismic zone factor
Terrain Category	3.0	Soil type
Structure Class	B	Importance Factor
Risk Coefficient & Topography	1.0	Response Reduction

Loading combinations were considered for the concrete design consisting of 1.4 factor of dead load and another combination of 1.2 factor of dead load with 1.6 factor of live load along with various other combinations were analysed for deflection and area of steel requirements at both bottom and top face for the critical load combination. Imposed loading were applied on the basis of crush carrying capacity of 6 persons per square meters i.e 60m^2 of area can accommodate 360 persons considering an average weight of 65kg the uniform loading coming onto the structure is upto 15kN/m.

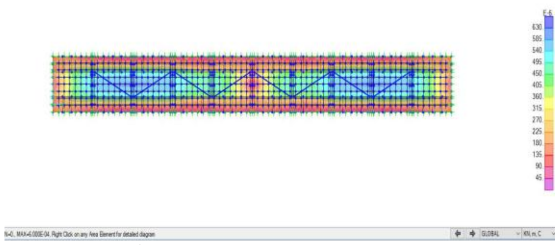
On analysis of proposed extended structure as shown in Fig 4 it can be seen the deflection obtained was about 2mm and the reinforcement along the longer direction required is 755mm^2 which on manual calculation was obtained as 601.65mm^2 similarly reinforcement along shorter direction required is 600 mm^2 to that obtained manually of 490.38mm^2.



(a) Deformed shaped contour



(b) Reinforcement intensity along longer direction



(c) Reinforcement intensity along shorter direction

Fig. 4: Girder modelling and analysis

4. Finite Element Modelling

The entire model is developed for finite element analysis in ABAQUS CAE software. Modelling of various parts involved steel girder, concrete slab and shear stud. Meshing is done using part by part basis such that the regular hexahedral mesh is generated. Due to symmetry of the structure only a single plate girder is considered for one- fifth of the span of the entire structure. Tie constraints and interface contact are applied between steel and concrete surfaces. Shear stud is assembled on top of steel girders by surface to surface contact method of interaction such that finite sliding is achieved. Material and geometrical details of steel concrete composite girder are provided in Table 3 and 4 respectively.

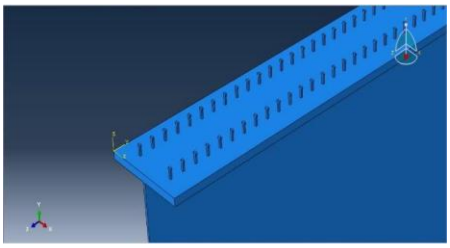
Table 3: Detail of Materials

Material Details	Description	Value
Concrete	Density ,kg/m3 Elastic Modulus , MPa Poisson's ratio	2500 30000 0.2
Steel	Density ,kg/m3 Elastic Modulus , MPa Poisson's ratio	7850 210000 0.3
Stud Connector	Yield Strength , MPa Ultimate Tensile Strength , MPa	680 900
Reinforcing bars	Yield Strength , MPa Ultimate Tensile Strength , MPa	415 550

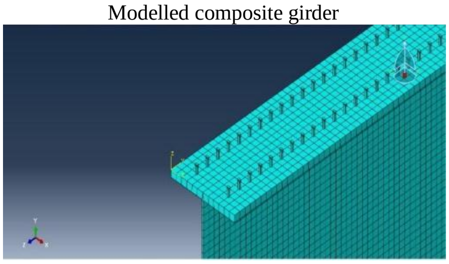
Table 4: Geometrical Details

Details	Geometry Specification	Value
Steel Concrete Composite girder	Total length of girder specimen,	4000
	Total number of stud connector	78
	Number of stud connectors per row	39
Steel Girder	Width of flanges, mm	600
	Thickness of flanges, mm	50
	Thickness of web, mm	15
	Total depth, mm	2100

Interaction of the stud - concrete is modelled by considering frictional parameter in tangential direction and hard contact in normal direction to avoid penetration. Coefficient of friction of 0.4 and tangential behaviour is considered for penalty method whereas in normal interaction hard contact option is used & the separation was allowed. The interaction between concrete slab and flange of steel plate girder of which concrete surface is modelled as slave surface whereas flange surface as master. Similarly the concrete surface around stud is modelled as slave and stud surface as master.



Modelled composite girder



Hexahedral meshed model

Fig. 5: Girder modelling

Steel composite concrete girder were modelled and assembled considering interaction and constrain parameters. Meshing of all the parts were done individually. End constraints at the supports were provided considering boundary condition. The loading is applied onto the surface in the form of pressure acting to the surface due to the applied loading i.e 12kN/m. The load distribution on analysis is as shown in Fig 6 which shows a varying stress distribution with tension and compression on ends of the girder. It is seen from Fig 7a and 7b the shear studs designed are capable of transferring load onto the girder from the slab and the stud shank develop stress varying along its height and perimeter.

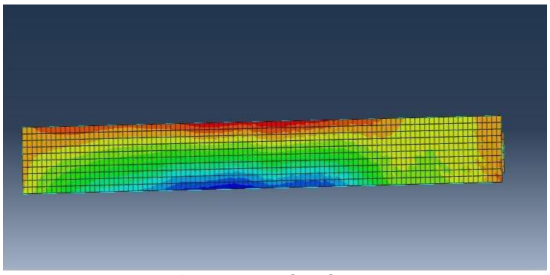


Fig. 6: Stress distribution

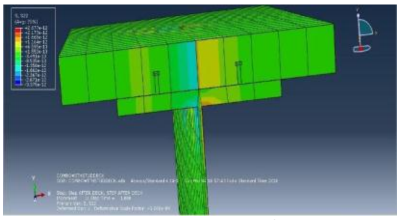


Fig. 7a: Load transfer

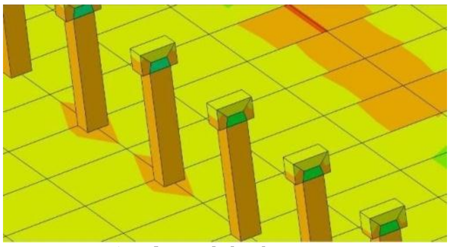


Fig. 7b: Stud shank stresses

The areas with red depicts member are in tension zone and the areas having blue depicts member are in compression zone. Shear studs are analysed for their efficiency. The numerical model gave a higher deflection for loading more than the ultimate load i.e upto 20% – 25%. At peak load the deflection was obtained to be around 2mm only. The hard contact between concrete surface and stud prevented slippage since the stud placing prevented it. The yield load was obtained to be 60% of ultimate load by elastic analysis.

5. Cost Analysis

The proposed platform of 20m is designed in such a way that it can be addition to the existing metro station provided on either side of the station thus providing a provision for addition of two more train cars. A single plate girder addition of 20m will allow an additional of 360 passengers to be transported. Quantitative estimation of a steel concrete composite plate girder is about Rs 24 Lakhs including both construction and fabrication cost whereas a single metro station costs upto Rs 22,373 Lakhs. The life cycle cost involved is minimum in case of steel concrete composite girder based on the criterion of design cost, construction cost, maintenance cost, rehabilitation cost, user cost and salvage value.

6. Results and Discussion

Passenger capacity for future purpose along with proposed headway were studied and a possible way of traffic management by providing an added extension platform comprising of plate girders, concrete slab was designed. On analysis of the designed structure it was found to undergo a maximum deflection of 2mm with a maximum bending moment of 22.27kN/m on the shorter span of the slab hence the main reinforcement distribution is along shorter span. Pier designed with 20mm diameter bar along longitudinal direction and 12mm diameter bar along transverse direction. Shear stud spaced closely prevented the slippage of the steel concrete surface. ABAQUS analysis gave an insight into the efficiency with which a shear stud forms a homogeneity of structure such that load and stress transfer takes place. Shear force resisted by connector is 140.16 kN/m with a single stud capable of carrying 109kN placed on the girder at a spacing of 100mm c/c.

7. Conclusions

1. Suitable form of any extension can be done using plate girder for elevated structures. In case of Kochi metro the possibility of future expansion without any temporary decrease in headway is apt.
2. Existing piers are through the median of the road which are designed for existing superstructure hence a cantilever pier is adopted spanning over the two way road.
3. Time required for construction of the extended platform using composite plate girder is minimal.
4. Cost involved in composite steel concrete girder is merely 25 lakhs which on comparison to any other mode of extension is the least.
5. Addition of platforms provides increment in the capacity of passenger flow during peak hour peak direction traffic.
6. The finite element analysis provides insight into the minute variation and distribution taking place in a structural component or its part.
7. Vibrations from the moving metro and the effect of wind at high altitude is to be taken care of by providing a viscoelastic damper along the diagonal member of the connecting plate girders.

References

[1] Nakamura SI, Momiyama Y, Hosaka T & Homma K, "New technologies of steel/concrete composite bridges", *Journal of Constructional Steel Research*, Vol.58, No.1, (2002), pp.99-130.

[2] Thondel S & Studnicka J, "Behaviour of steel-concrete composite beam with high ribbed deck", *Procedia Engineering*, Vol.40, (2012), pp.457-462.

[3] Yin GA, Ding FX, Wang HB, Bai Y & Liu XM, "Connection performance in steel–concrete composite truss bridge structures", *Journal of Bridge Engineering*, Vol.22, No.3, (2016).

[4] Ahn Y, Kowada T, Tsukaguchi H & Vandebona U, "Estimation of Passenger Flow for Planning and Management of Railway Stations", *Transportation research Procedia*, Vol.25, (2017), pp.315-330.

[5] Berthellemy J, "Fatigue designed CL-cutting shape: A new economic steel-concrete connection system and some applications for bridges", *Procedia Engineering*, Vol.66, (2013), pp.138-149.

[6] Chen YT, Zhao Y, West JS & Walbridge S, "Behaviour of steel–precast composite girders with through-bolt shear connectors under static loading", *Journal of Constructional Steel Research*, Vol.103, (2014), pp.168-178.

[7] Nie X, Yang Y, Fan J, Mo YL & Nie, J, "Experimental Study on Steel Jacket–Concrete Composite Connections", *Journal of Bridge Engineering*, Vol.22, No.4, (2016), pp.04016138.

[8] Machelski CZ & Toczkiewicz R, "Effects of connection flexibility in steel-concrete composite beams due to live loads", *Archives of Civil and Mechanical Engineering*, Vol.6, No.1, (2006), pp.65-86.

[9] Morlok EK & Nitzberg BF, "Reducing boarding and alighting accident rates on mixed high and low platform railroad lines through car and station design", *Journal of transportation engineering*, Vol.131, No.5, (2005), pp.382-391.

[10] Sung YC, Lin TK, Chiu YT, Chang KC, Chen KL & Chang CC, "A bridge safety monitoring system for pre stressed composite box-girder bridges with corrugated steel webs based on in-situ loading experiments and a long-term monitoring database", *Engineering Structures*, Vol.126, (2016), pp.571-585.

[11] Briseghella B & Zordan T, "An innovative steel-concrete joint for integral abutment bridges", *Journal of Traffic and Transportation Engineering (English Edition)*, Vol.2, No.4, (2015), pp.209-222.

[12] Deng, Y. *Efficient pre stressed concrete-steel composite girder for medium-span bridges*. The University of Nebraska-Lincoln, (2012).

[13] Ellobody E, "Interaction of buckling modes in railway plate girder steel bridges", *Thin-Walled Structures*, Vol.115, (2017), pp.58-75.

[14] Odrobiňák J, Bujňák J & Žilka J, "Study on short span deck bridges with encased steel beams", *Procedia Engineering*, Vol.40, (2012), pp.333-338.

[15] Samali, B & Kwok KCS, "Use of viscoelastic dampers in reducing wind-and earthquake-induced motion of building structures", *Engineering Structures*, Vol.17, No.9, (1995), pp.639-654.
[16] Plain IS, *Reinforced Concrete–Code of Practice* (4th Revision), (2000).
[17] Standard BI, "General Construction in Steel-Code of Practice", 3rd *Revision, Bureau of Indian Standard, New Delhi, India, IS,* (2007), pp.800-2007.
[18] Specifications S, Code of practice for Road Bridges. *Section–II, Loads and Stresses-Fourth Revision, IRC*, 6-2000, (2000).
[19] Indian Road Congress.: Standard Specifications and Code of Practice for Road Bridges – Composite Section, IRC 22, (1986).
[20] Ramachandran M, *Metro rail projects in India: a study in project planning*. Oxford University Press, (2011).