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# Design of Flyover Construction based on Fibre Reinforced Concrete and Timber Pile Foundation

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**Abstract**

An overpass of 1.5 km length and 12.5 m width is built with the help of advanced hybrid technology in-order to support all kinds of vehicles simultaneously without delay. The project stands unique from other construction systems where the deck and pile foundations are comprised of massive timber-concrete vertical support via earth matters up-to the rock layers. The girders of the superstructure are made of fibre reinforced concrete. The design, from its initial stage till its completion, is represented with necessary diagrams. The construction undergoes a series of tests to confirm its stability and durability.

**Keywords:** Deck, Pile foundation, Timber-concrete composite, Fibre reinforced concrete, Girder.

## INTRODUCTION

[1, 2] It is generally assumed that the flyover is related to the bridge constructed over road or railway tracks as how they are often could be seen in order to deal with heavy traffic. The construction is not limited to that alone, rather it is advantageous to conduct other activities under the construction if the spaces also as they are left empty. High-rise structures might get damaged due to over man-made loads. There are flyover collapses occurring while construction, due to the instability of the substructure. Construction of newer ones in the place of previous ones may lead to economic loss. Repairing/maintaining the damaged structure, though essential, building of such structures with longer life span is also unavoidable.

It is also necessary to eliminate the over bridges that remain futile and which pose a threat to the environment. The fact is that, their roles are productive at the beginning stage and as days go on, they lose their originality in the sense of reduction in their structural stability. [3, 4] In the construction of over bridges, loop/ square topologies were addressed to help in concluding which one suits more. Proper planning is the most important thing and only after sufficient testing, the built structures must be left for service. [5] Occurence of problems are common when considering the oversized trucks into account. Smart systems were introduced which deliberately alarm when oversized vehicles head to the flyover. In this case, these vehicles are stopped for a while to pave way for other vehicles to leave from the bridge in-order to avoid collision. Since this approach is costlier, computer aided mechanism replaces the previous one. Still, this system delays the vehicles and makes them wait. So, an ideal flyover construction must be built that is strong enough to hold any number of huge vehicles that passes by. [6] Vibro pile construction is elaborated where 318 piles are considered for analysis. It is stated that this type of pile foundation could be preferred for low-volume overpasses. [7] Continuous flight auger piling system was used which is highly recommended in areas where the water table volume is more. Extensive studies and experiments are essential to verify its structural integrity by ensuring apt auger rotation. Furthermore, by economic means, it is not suitable for low budget constructions.

[8] The buildings constructed using lightweight concrete was described that are suitable for all types of bridges including reinforced concrete, post tensioned girder structures, etc., and with the help of these, subsequent mass and cost savings could be achieved. Although it was proved to be durable enough like any other high weight materials, unsatisfactory results were also likely to be attained due to low quality control. [9] Bridge pier testing such as core and pull-out/off tests are conducted to determine the basic functionalities including thickness, elastic modulus, structural integrity, surface absorption, etc. From the case study of the T-beam girder made of concrete, it is found that the strength of the piers should have been improved by adding reinforcement or other means. [10] By the inclusion of reinforced concrete, occurrence of disintegration of structures because of beam-column interaction is preventable.

It also focussed on increasing the thickness of beam structures [11], since it contributes to building collapse resistance. [12] Steel reinforced concrete girders fail under fatigue behaviour test and such concrete composites [13] were not able to carry extreme loads. Hence for high rise structures, this type of mixtures is better to be avoided. [14] Piles are drilled in the form of balanced cantilever. In this given construction, the piles were of different sizes and length. Here, the cross section of the piers is constant. The entire layout is structured out of concrete. Other than this, the proposal was well framed. [15-16] Fibre reinforced polymer construction was opted for designing decks. It is said that these implementation process is complex but the merits are unlimited which include, ease of usage, less maintenance and better performance. In contrast, it is also necessary to note its shortcomings such as, low impact resistance, cost and flexural strength, where it cannot be recommended for heavy truck loads.

As both the steel reinforced structures and fibre reinforced

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polymer could not meet the design criteria, an innovative strategy is proposed making use of steel/polypropylene fibre reinforced concrete material. Prior to the construction, one must be careful in taking into account the soil suitability. Since the project focuses on wooden piles too, the soil type might not affect a lot. Still the usage of concrete piles would have an impact over them. So, whatever may be the piles' type, precautions and the requirements for the upper structure should be predicted beforehand. It is important to mark that all the shortcomings of the referred papers are overcome,

- Ground portion could be cleared to conduct other activities other than transport services.
- High structural and flexural strength - collapse resistance.
- The main objective is to bring traffic free network, and so if the flyover construction itself makes the individuals/ vehicles to delay, then, there is no use in building it. As it is mentioned, no such smart systems might be fully acceptable in dealing with delays, where this designed bridge is wider (12.5m) and stronger (validated) to hold multiple trucks simultaneously.
- Problems are common with unreinforced concrete materials; hence this drawback is also controlled by the use of steel/polypropylene fiber reinforced concrete.
- High impact resistance.
- Less maintenance, so in this regard, saves cost too.
- Usage of steel and concrete is minimised to certain extent, thus ecologically benign.

## CONSTRUCTION

As planning is vital ahead of starting the construction design, initial plan is drawn as shown in figure 1. Superstructure and substructure are the two major parts in the building where the pile foundation alone comes under substructure. The main portions of the superstructure include the pile cap, pier, pier cap, girder and deck surface. Since unreinforced concrete is not suitable for high rise buildings due to their incapability in withstanding heavy trucks as they lack tensile strength, reinforced concrete would be a right option. Again, in choosing apt reinforcement, a lot of test procedures are carried out to find out the suitable one.

Based on the literature reviews and a set of experiments, the blend of steel and polypropylene fibre enriched concrete is chosen as the fundamental building material. Steps are taken in the viewpoint of pollution and quality control as well, and so timber blocks also play a good role in the construction. Since it is also inevitable to work on a construction on the basis of long term usage, wood panels are limited by the implementation of reinforced concrete structures.

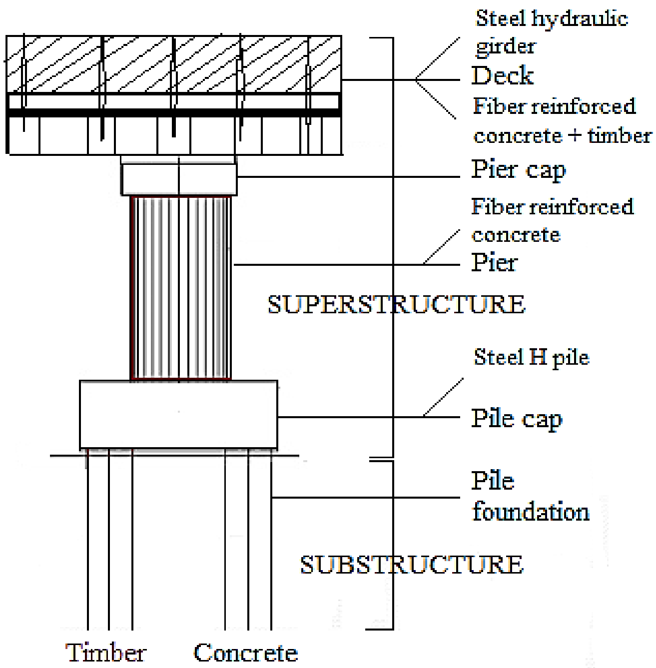


**Figure 1.** Project plan

### Substructure

***Pile foundation (beneath the foundation/earth)***

Pile foundation is the deep structure which conveys the top layering building to the sub/under earth. Positioning of piles is accurately done after analysing its pile-soil interaction, moisture effect, etc. The substructure supports the entire bridge and so its framework is emphasised in the project. In general, piles in construction can be made of wood or steel or concrete. It is lengthened till its dead end reaches a rocky area if it is made of concrete or steel because it might get corroded by other moisture/soil material. If it could land in a hard rock-like portion in the underground, then its structural strength is enhanced and become capable to hold any number of vehicles or trucks over its superstructure. When the same is being built using massive timber block, no such end is usually adopted and that could be placed anywhere. The pile foundation must be strong and durable. At the same time it should not pollute the nature. Hence a novel strategy is thus proposed where timber piles are also a part of deep foundation. The whole system cannot take timber piles as it might not be endurable for heavy structures, but the advantage of using this is, that it lasts long when it is used below ground water table other than any other materials. If it could be used above the ground water table, then prior to the settlement, timber must be pressure treated with preservation mechanisms. The proposed construction employs timber in certain deep foundations below the ground water table as a massive load, from where the reinforced concrete piles emerge. The design is based on drilled piling technique. The built piles are of 1700mm in diameter and its length varies from 20 to 40m. These get firmly fixed in-between or over the rock layers. The piles formations are validated by load testing.

**Figure 2.** Pile foundation

The two different types of foundations that are employed in this work are portrayed in figure 2. The portion of the structure that is stressed more is the foundation which requires multiple design strategies and formulations and the photograph of this initial workout is given in figure 3 and 4.

**Figure 3.** Initial processing of substructure

**Figure 4.** Superstructure where the upper bridge begin

The structure connecting the superstructure and the pile foundation denotes the end abutment to impart vertical and lateral reinforcement of the overpass. Pier can be defined as how abutment is stated. Both the pier and abutment structures do a great to strengthen the building. The piers are constructed with variable cross sections as there are several columns included.

**Superstructure**

Pier (vertical support), girder (horizontal support beam) and deck (surface of the bridge/ uppermost layer) are the elementary parts of the superstructure. The cross section is of 4m long and 3.4m wide, where the total width of superstructure and the wings are 12.5 m and 3m respectively. The density of the deck varies from 300 to 450mm depending upon the edge joint in between them and for girder it is variable from 680-800mm.

***Pile cap***

Pile caps also come under superstructure where this is the actual basement or the foundation that is visible. They are manufactured by steel H-piles that are capable to withstand tensile loading. After subjecting to static tests and numerical analysis, it confirms its effectiveness in conveying lateral, static and vertical loads.

***Pier***

Pier is grouted and then subjected to non-destructive test procedures. Pier is 2 to 3.5m (lower layer) and 15m (upper layer) from the ground where its diameter is relatively 2 m. In the pier construction, the grid size would be 1 m along perimeter and 1.5 m through its height. The ingredients of pier construction is steel/polypropylene fibre reinforced concrete where special bonding is applied externally to the concrete layers that aids in strengthening of horizontal beam and shear wall structures.

***Pier cap***

Polypropylene fibre reinforced concrete is applied in the process which improves impact and abrasion resistance. The significant thing is that it decreases the requirement of steel reinforcements that is normal in the case of pier construction. Usage of both the steel and polypropylene reinforcement in pier and pier cap structure improves the overall structural strength, ductility and durability. Since both forms of reinforcements are used, freeze-thaw resistance is also enhanced.

***Girder***

The construction is pre-stressed in which its shear behaviour is determined. In the normal process, girders and cross beams make use of large quantity of steel which is highly expensive. Hence a feasible approach is designed using hydraulic girders by mirror function or strength theory so that the girder's ideal form with variable or uniform cross section can be assessed. Direct stress can be stated by,

$$\sigma_{ic} = \frac{N_{ic}}{F_{ic}} + \frac{M_{ic}}{W_{ic}} \tag{2.1}$$

where $\sigma_{ic}$ is the normal stress at a point i and $N_{ic}$ and $M_{ic}$ relate to internal stress of the specimen.

By calculating potential energy and by inducing a strength criterion, general form of non-linear model of the beam can be determined by,

$$V_i = F_i l_i = \sqrt{\sum_{j=1}^{n} \sum_{k=1}^{n} A_{ijk} x_j x_k + 2 \sum_{j=1}^{n} B_{ij}\, x_j + C_i} \quad (2.2)$$

where $F_i$ and $l_i$ are referred as cross sectional area and length of the testing material respectively and $V_i$ refers to specimen capacity. Thus by this type of girder construction, the total steel usage is lowered by 15%.

### *Deck*

Deck can be of several types. In this construction topology, timber and concrete composites are used as the deck constructive materials which are highly rigid and lower in dynamic defects. The physical properties of timber and concrete substances vary with respect to hygro-thermal dissimilarities which in turn result in strain of the materials, thus, elevating their deflection and internal stress. The relative humidity and pressure that goes on changing influence the structure's deflection. On taking account of all these aspects, a proper model is constructed by subjecting it to bending test. At first, screwed connection is performed by the composites. The experiment is conducted with the beam of length and width 9 m and 1100 mm respectively. The wooden strand with adhesives is compressed to form particle board. Timber is coated with the layer of particle board where its density would be around 25 mm and these structures are over-coated by 75 mm-steel fibre reinforced concrete. The concrete and timber structures are connected by means of brass screws which is 200 mm long. This kind of beam is sensitive to the atmospheric changes and by this method the annual deflection is found to be 5 mm. So, in order to minimize this effect, the depth of timber plank is reduced by increasing the concrete's density so that even at extreme temperature and humidity changes, this approach is practicable.

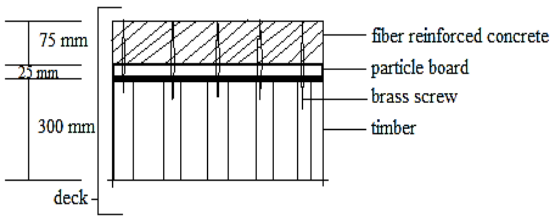


**Figure 5.** Layout of deck: screwed connection

The basic design for deck construction is given in figure 5. The lower structure of the flyover might not be in equal length from the ground and for lower levels, the supports are provided as shown in figure 6.

**Figure 6.** Pier: Lower (first layer) supporting superstructure

The same supporting unit for maximum length from the ground level can be constructed as shown in figure 7.

**Figure 7.** Pier: First layer of superstructure

The topmost structure of the building is represented in figure 8.

**Figure 8.** Pier: Second layer of superstructure

## RESULTS AND DISCUSSION

To validate the construction materials used in the above structure, compressive and tensile strength along with shrinkage and permeability tests are carried out wherever fibre reinforcement concrete is employed.

### Tensile strength

The tested concrete is the polypropylene reinforced and steel/polypropylene fibre reinforced material. To assess it, the formula used is,

$$T_s = \frac{2F}{\pi L d}\ MPa \qquad (3.1)$$

where, $T_s$ is the tensile strength, F denotes the maximum load, L is the total length of the test specimen and d the dimension of the cross section.

It is understood from table 1 that as the fibre content increases for the polypropylene reinforced concrete type, tensile strength increases till 0.2%, and upon further enhancement in its percentage, the strength degrades. It is measured in terms of force per cross sectional area.

**Table 1.** Polypropylene fibre reinforced concrete-tensile strength

| % of fibre | Tensile strength (MPa) |
|---|---|
| 0 | 2.8 |
| 0.1 | 3.8 |
| 0.2 | 4 |
| 0.3 | 3.9 |

In case of compact polypropylene/steel fibre reinforced concrete type, the tensile strength increases with that of increase in fibre content and is plotted in table 2. Figure 9 depicts the bar chart for tensile strength versus fibre ratio, when polypropylene enriched concrete is used.

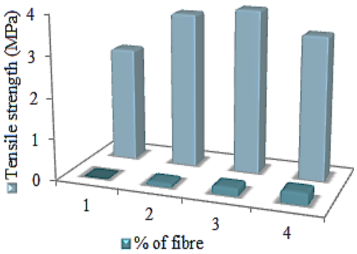


**Figure 9.** Tensile strength of polypropylene reinforced concrete

**Table 2.** Polypropylene/steel fibre reinforced concrete-tensile strength

| % of fibre | Tensile strength (MPa) |
|---|---|
| 0 | 2.8 |
| 0.1 | 4 |
| 0.2 | 4.5 |
| 0.3 | 5 |

Initially ordinary concrete without adding any fibre content to the mixture is kept under tensile strength. The second, third and fourth samples are proportionally mixed with fibre in the ratio of 0.1, 0.2 and 0.3 percentage with respect to the concrete volume. By adding 0.1% of steel/polypropylene fibre to the concrete composite, the tensile strength enhances by 40% and addition of 0.3% gave the maximum tensile strength.

### Compressive strength

Compressive strength of steel fibre reinforced concrete enhances with its addition as given in table 3.

**Table 3.** Steel fibre reinforced concrete-compressive strength

| % of fibre | Compressive strength (MPa) |
|---|---|
| 0 | 36 |
| 0.1 | 40 |
| 0.2 | 42 |
| 0.3 | 39 |

By adding polypropylene reinforced concrete by 0.3%, the compressive strength rises up to 43% and above 0.3%, it decreases and hence utilising steel/ polypropylene blend fibre reinforced concrete would give better results in enhancing compressive strength. Its corresponding plot is given in figure 10.

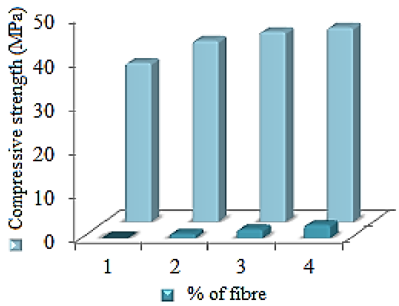


**Figure 10.** Compressive strength for steel/polypropylene fibre reinforced concrete

### Absorbent test

Permeability of water and gas level has been tested separately by setting the specimen in the testing equipment. The pressure and time period for the procedure would be 450±100 kPa and 45±5 hours respectively. Then, water absorption has been tested by splitting the specimen into half and the penetration depth is determined. For gas permeability too, the procedure is same but the test apparatus is different and the time period is 28 days. Addition of fibre in the ordinary concrete increases the water absorbent rate from $4.04*10^{-12}$ m/s to $13.5*10^{-12}$ m/s where the coefficient of gas permeability rises from $42*10^{-10}$ $m^2$ to $74.45*10^{-10}$ $m^2$.

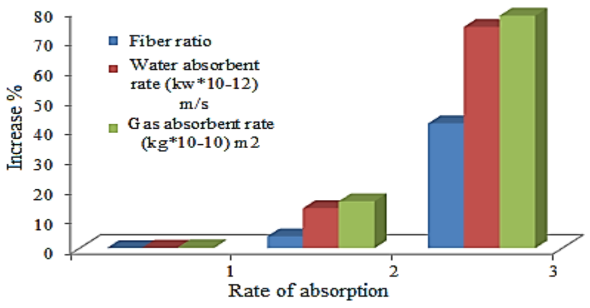


**Figure 11.** Permeability rate

The diagram showing the gas absorbent rate is given in figure 11. For the steel/polypropylene blend nature, the corresponding data is provided in table 4.

**Table 4.** Water and gas absorption

| Fibre ratio | Water absorbent rate (kw*$10^{-12}$) m/s | Gas absorbent rate (kg*$10^{-10}$) $m^2$ |
|---|---|---|
| 0 | 4.04 | 42 |
| 0.2 | 13.5 | 74.45 |
| 0.3 | 15.8 | 78.2 |

**Shrinkage/contraction test**

The separate composite mixtures are poured over a slab and the occurrence of cracks is constantly checked by setting the temperature and relative humidity at 35℃ and 60% accordingly. In certain cases it is seen that the plain concrete results crack after 2 hours of construction settlement which broadens further. The same concrete when enriched with fibre in lower percentage, the emergence of crack happens only after 9 hours of settlement. When the ratio of fibre is more, cracking is almost prevented. Comparing to ordinary concrete, addition of fibre by 0.3% reduces the composite’s shrinkage by 90%. This is represented in table 5.

**Table 5.** Crack reduction

| % of fibre | Total crack % | Crack reduction |
|---|---|---|
| 0 | 15 | 0 |
| 10 | 9 | 40 |
| 20 | 5 | 87 |
| 30 | 0.1 | 99 |

From figure 12 it is clear that including fibre in the plain concrete material prevents shrinkage or contraction.

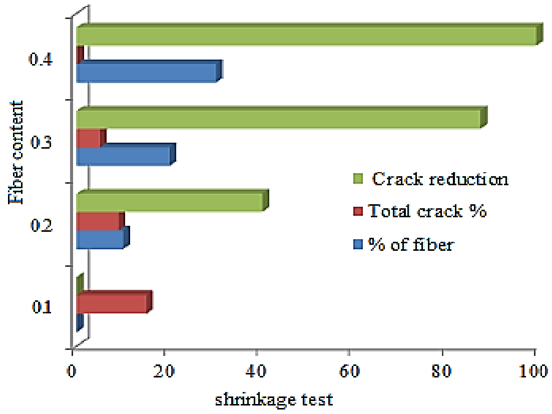


**Figure 12.** Crack reduction as fibre increases

Steel and polypropylene blend reinforced concrete stands firm under fatigue test too, where the concrete materials are unable to withstand it. As in figure 13, the crack formation gets delayed. The picture displays crack reduction from 0.2% to 0.3% increase of fibre.

**Figure 13.** Contraction test by addition of fibre

Although the usage of concrete is minimised, total reduction is not permitted due to its significant role in structural properties. Usage of reinforced concrete reduces the existing drawbacks concerning environmental pollution too.

## CONCLUSION AND FUTURE RECOMMENDATIONS

Structural enhancement is vital in construction, where, somehow the ultimate strength of the structure must be prioritised. This project is not limited with such basic parameters alone, but also is built in accordance with serviceability and build-ability. Erecting of high rise structures would be in vain if they do not meet the design criteria or performance limit. Such constructions are given preference more than ordinary buildings since it is built in-order to withstand heavy vehicles and loads. Therefore maximum efforts are taken in choosing the building material for each sub parts and the results are validated in terms of long term efficiency. The overall usage of cement products can be minimized as these stands high in polluting the environment. So engineers must be trained enough by trying their hands in employing materials that goes well with the nature and its surroundings or recycling of leftover must be put into practise at once the construction gets over.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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