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Analysis and Design of Hot Metal Track (Ballast-Less Track) using STAAD Pro

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Abstract **- In industries like Cast Iron pipes production, transportation of hot metal (more than 1700ºc) lies a major feedback for the continuous conveying of metal to the production unit through the road transportation. In this paper, rail road for a span of 212m stretch at the existing road level is designed as per the rail load details provided by the industry. To design in an economical way, rather than excavating for the whole span, it is designed to bear the track on top of a concrete frame laid parallel beneath the track formation with excavation work done only to the footings provision. IRS - 52 kg track along with fixture plate (base plate) is used to form the track.**

Keywords - Column, Beam, Tie beam, Footing, IRS-52 track, Base plate, Anchor bolt

I. INTRODUCTION

Formation of conventional track includes large amount of earth material excavation, formation of base layer, sub-base layer, ballast layer and sleeper beams. This is optimal for a large span of track formation. In this case, as the span is limited to 212 metres, to reduce the cost and effective utilization of resources available near the site, concrete structure alike track is formed. Also the earth work to be done is less optimized. By this method of track formation, regular routine work in the industry work is unaffected and also consumes less time and resources used.

As per the company requirements, a track that transfers hot metal within the industry for a span of 250 metres is to be formed. There lies a major criterion that the construction work should not affect the primary work of industry i.e., the road transportation that is lying parallel to the proposed site. Based on the constrains in the industry an attempt has been made to have a ballast-less track formation.

The train specifications are as provided by the machineries department of the industry itself such as

Length of rail = 7.18 m (wheel to wheel)

ballast-less track formation.

The train specifications are as provided by the machineries department of the industry such as

Length of rail	=	7.18 m (wheel to wheel)
Load per wheel	=	30 tons
Width of rail	=	1.746 m (track centre to centre)
Rail track to be used	=	IRS 52
Total length of rail	=	12.51 m.

A review of literature states that the solid specimen has higher cracking, ultimate load capacities and energy absorption. However the load deflection curves were coincident up to the linear limit as per Madhkhan et al [1].

Konstantinos et al [2] explained that the application of slab track and embedded track in railway network creates the need for transition zones, between ballast-less and ballasted track sections. It is seen abrupt changes in stiffness of the members. It is also found that the transition zones guarantee a smooth stiffness transition between slab track and ballast-bed, resulting in a smooth variation of the forces that act on the track.

Dielemen et al [3] stated that it was possible to carry out a very short slab thickness structure with the STEDEF system adapted to high speed. The result is constraint stress level obtained is rather low, which allow using concrete with standard characteristics.

Compared to the model with relatively small crack length, large crack lengths (0.20 m) results in higher Stress Intensity Factors (SIF) and consequently lead to higher crack growth ratio and therefore large crack length might speed up the destruction of the structure as per Shengyang et al[4].

From the above literature survey, it is inferred that solid members acquire more stiffness than ballast-bed and also a smooth variation of forces to be transferred from the track.

II. PROJECT INPUT DETAILS

Track length	= 211 m
Length of rail	= 7.18 m (wheel to wheel)
Load per wheel	= 30 (tons)
Width of rail	= 1.746 m (track centre to centre)
Length of each span	= 7 m
Rail track to be used	= IRS 52
Total length of rail	= 12.51 m

Safe Bearing Capacity of soil= 23 tons/m^2

III. LOAD CALCULATION

(i) Dead load calculation

Self weight of beam

- Main beam = 25 x 0.5
  = 12.5 kN/m
- Tie beam = 25 x 0.3
  = 7.5 kN/m
- Column = 25 x 0.6
  = 15 kN/m

(ii) Equipment load

As provided by the machinery description, Load per wheel = 30 tons = 300 kN. To have maximum Bending Moment for the beam, load is considered to be placed at centre of beam i.e., (7/2 = 3.5 m) each span.

(iii) Rail load

IRS 52 Kg/m or 105 lbs, Bull-headed rail is used. Figure 1 shows the dimension of the bull-headed rail under study.

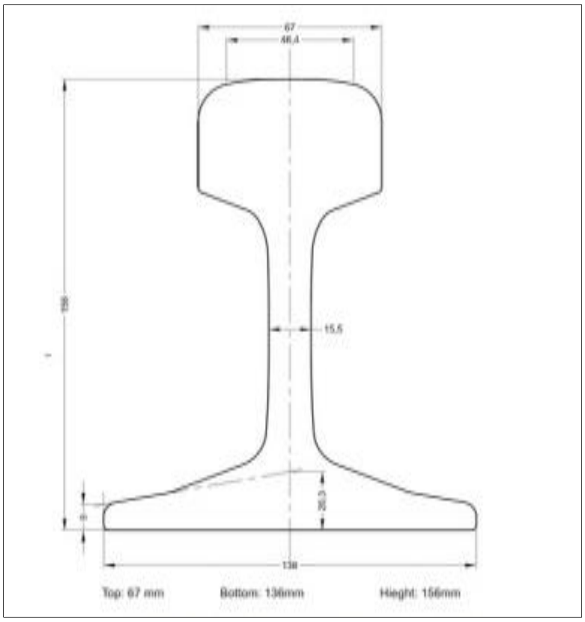

Fig. 1 IRS-52 kg rail dimensions.

III. ANALYSIS

(a) Model creation

The model is created using STAAD Pro V8i software (Figure 2). Each span is 7m (column to column) and the column height is fixed as 2.05 m. The structure is formed with concrete sections such a column (600 x 600 mm), main beam (500 x 500mm) and a tie beam of (300 x 300mm). End buffer is formed on both sides with steel sections in order to encounter a large horizontal force of 30 tons. (Figure 4).

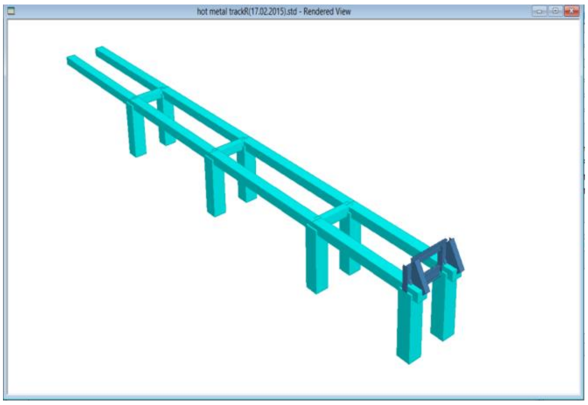

Fig. 2 Rendered view of the whole structure.

(i) Load case details

The loads that have been calculated are applied to the structure along with load combinations as shown in Figure 3.

The load cases are

- Dead load
  i. Self weight
  ii. Self weight of track (52 kg)
  iii. Dead load of train (300 kg)
- Track load (concentrated)
  i. Concentrated load on beams (375 kN)
  ii. Concentrated load on end buffer beams(375 kN at 2.5 m)
  iii. Horizontal load due to moving train (375 kN)
  iv. Horizontal load on end buffers (375 kN) (as shown in figure 4)
- Track load (uniform load)
  i. Uniform load on beams (107 kN/m)
  ii. Uniform load on end buffer beams (53.5 kN/m)
- Load combinations
  i. [Dead load + Track load(conc)] x 1
  ii. [Dead load + Track load(udl)] x 1
  iii. [Dead load + Track load(conc)] x 1.5
  iv. [Dead load + Track load(udl)] x 1.5

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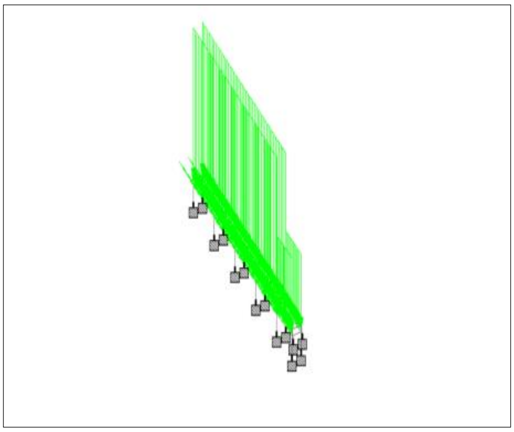

Fig 3. Structure with load combination

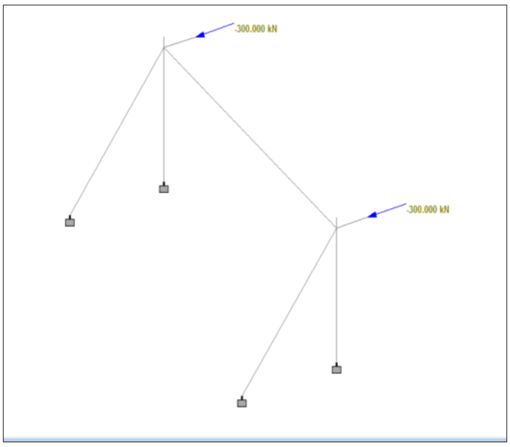

Fig 4. End buffer with horizontal loading.

(ii) Reactions and Moments

The maximum reactions and moments obtained from the analysis are given in Table 1. The structural design is carried out using these maximum values.

Table 1 Maximum reactions and moments

Reactions/Moments	***Values***
Max Fx	0.514 kN
Max Fy	1197.34 kN
Max Fz	295.56 kN
Max Mx	28.49 kNm
Max My	0.001 kNm
Max Mz	0.284 kNm

IV. DESIGN

(a) Concrete design

Concrete design is carried out for main beam,s tie beam and column. Grade of Concrete used is M30 and Grade of steel used is Fe415. Maximum size of reinforcement rod to be used is 20 mm diameter and Minimum size of reinforcement rod used is 8 mm. Cover for beams provided is 25 mm and for columns 40 mm. The column (600 x 600 mm) design details of a typical column are given below.

Typical column design

Grade:

- Concrete - M30
- Reinforcement - Fe415

i. Length - 2050 mm
ii. Cross section - 600 x 600 mm
iii. Cover - 40 mm
iv. Guiding load case - 6 (D.L+T.L(udl)x1.5)
v. Type of column - Short
vi. Required steel area - 3650.19 sq.mm
vii. Required concrete area - 356349.81 sq.mm
viii. Main reinforcement - Provide 12-20 mm dia (1.05%, 3769.91 sq.mm) equally distributed
ix. Tie reinforcement - Provide 8 mm dia, Rectangular ties @800mm c/c.
x. Worst load case - 6 (D.L+T.L(udl)x1.5)
xi. Pu_z = 5982.49 kN
xii. Mu_y = 470.03 kNm
xiii. Mu_z = 470.03 kNm

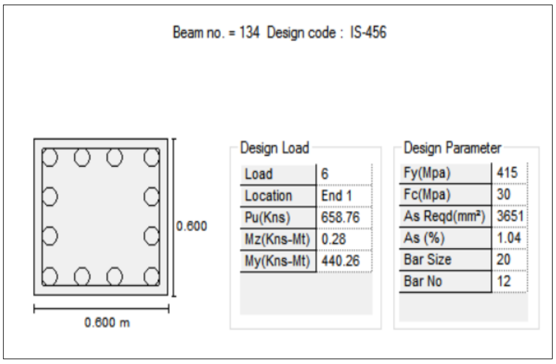

Fig 5 Typical column reinforcement details

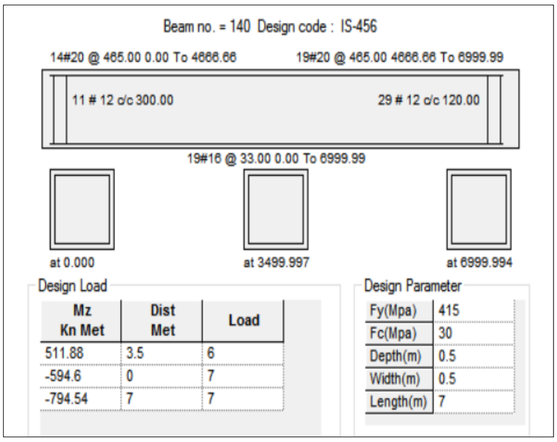

Fig 6 Typical main beam reinforcement details

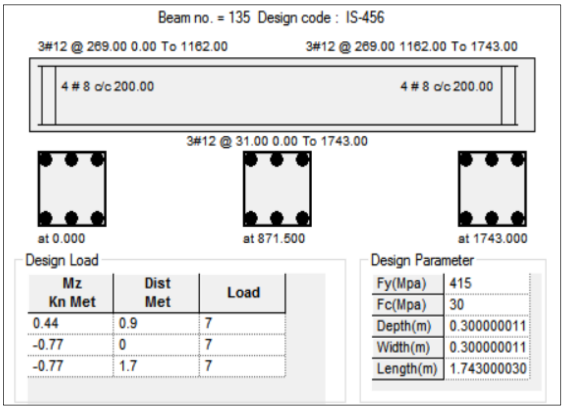

Fig 7 Typical tie beam reinforcement details

(b) Steel design

The End buffers are formed with steel sections such as ISMB 200, ISMB 300 and ISMB 600 sections. The connections are welded using gas welding. The steel section is connected to the concrete beam using Base plate and Anchor rods placed during casting of concrete member.

```
ALL UNITS ARE - NEWT MMS  (UNLESS OTHERWISE NOTED)

MEMBER    TABLE       RESULT/   CRITICAL COND/      RATIO/     LOADING/
                        FX          MY                MZ       LOCATION
=======================================================================

   228 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.2          0.925        6
             440148.56 T  30710750.00       -3076.64          717.00
   229 ST   ISMB200                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(A)       0.003        6
                119.78 C      103.14        91274.05            0.00
   230 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.2          0.925        6
             440148.56 T  30710750.00        3076.64          717.00
   231 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(B)       0.537        6
             654468.44 C    -2856.46  -129187072.00           903.65
   232 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(B)       0.537        6
             654468.44 C     2856.46  -129187072.00           903.65
   233 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.2          0.767        6
             388822.91 T -25024792.00        3076.61            0.00
   234 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.2          0.767        6
             388822.91 T -25024792.00       -3076.61            0.00
   235 ST   ISMB200                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(A)       0.003        6
                119.78 C     -103.13        91274.05            0.00
   236 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(B)       0.588        6
             616050.56 C    -2856.44  -163099744.00             0.00
```

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ALL UNITS ARE - NEWT MMS  (UNLESS OTHERWISE NOTED)

MEMBER    TABLE       RESULT/   CRITICAL COND/      RATIO/     LOADING/
                        FX          MY                MZ       LOCATION
=======================================================================

   237 ST   ISMB600                (INDIAN SECTIONS)
                          PASS     IS-7.1.1(B)       0.588        6
             616050.56 C     2856.44  -163099744.00             0.00
   238 ST   ISMB300                (INDIAN SECTIONS)
                          PASS     7.1.2 BEND C      0.003        6
                  8.25 T        0.65       156495.45            0.00
   239 ST   ISMB300                (INDIAN SECTIONS)
                          PASS     7.1.2 BEND C      0.003        6
                  8.25 T       -0.65       156495.45            0.00
```

Fig. 8 Steel design details

(c) Footing design

From the reactions obtained from the output and the input data values, footing design for the maximum axial loading and moment is calculated. This design gives the required footing area and depth to be provided to encounter the large loads.

(i). Data:

Column size = 600 x 600 mm

Axial load, P = 1200 kN (from result)

Bearing capacity of soil, SBC= 23 Tons/m^2

Concrete Grade = M30

Grade of steel = Fe415

(ii). Assuming the weight of combined footing plus backfill to constitute 15% of column loads,

A_{reqd} = (P_1 + P_2 + ΔP)/ Safe Bearing capacity of soil

= (1200 + 1200)x1.15/ 230

= 12 m^2.

(iii). Assuming a load factor of 1.5, the factored column loads are,

P_{u1}, P_{u2} = 1.5 x 1200

= 1800 kN.

P_{u1} + P_{u2} = 3600 kN.

(iv). Spacing between columns, S =1743 mm.

$$x = \frac{P_{u2} \times S}{P_{u1}+P_{u2}}$$

= 1743 mm.

As x > S/2 = 871.5 mm, Rectangular footing is provided with length,

L = 2(1743+300).

= 4086 mm.

∴Provided L= 4.1 m.

Width, B $\geq$ A/L = 12/4.1

= 2.92 m.

∴Provided B= 2.95 m.

Stress resultants in longitudinal direction:

(v). Treating the footing as a wide beam (b=2950 mm) in the longitudinal direction, the uniformly distributed load is ,

$q_uB = (P_{u1}+P_{u2})/L$
$= 3600/4.1$
$= 878.04$ kN/m.

(vi). Distribution of shear force is shown.

The critical section for one way shear is located at a distance d from inside face of column C_2, and has a value

$V_{u1} = 1800- 878.04[1178.5+300+d]\times10^{-3}$

(vii). Distribution of Bending Moment is shown.

The maximum positive moment at the face of column C_2 is

$Mu^+ = 878.04\times(1.1785-0.3^2)/2$
$= 338.8$ kNm.

The maximum negative moment at x

$= 1600/878.04$
$= 1.822$ m.

$Mu^- = 878.04\times(1.822)^2/2- 1600\times(1.822-0.3)$
$= 1457.4-2435.2$
$= -977.8$ kNm.

Thickness of footing based on shear:

viii). One-Way shear, V_{u1}:

$\tau_c = 0.4$ for M30

and $P_t = 0.3$

$V_{uc} = 0.4\times2950\times d$
$= 1180\times d$ in N.

$V_{u1} \leq V_{uc} \Rightarrow$

$1800-878.04(1478.5+d)\times10^{-3} = 1180\times d$

$\Rightarrow d \geq 424$ mm.

∴ Provided 450 mm depth.

(ix). Two-Way shear, V_{u2}:

Factored soil pressure, $q_u = q_uB/B$
$= 878.04/297$ kN/m^2.

Assuming d $= 450$ mm.

$V_{u2} = 1600- 297(0.6+0.45)(0.6+0.45/2)$
$= 1342$ kN at C1
$= 1600- 297(0.6+0.45)^2$
$= 1272.55$ kN at C_2.

Limiting two way shear stress,

$\tau_{c2} = k_s(0.25\sqrt{f_{ck}})$

here $k_s = 1.0$ for square columns.

$\therefore \tau_{c2} = 1\times0.25\times\sqrt{30}$
$= 1.369$ MPa.

$V_{uc} = 1.396\times(1050+420\times2)\times450$
$= 1.164\times106$ N
> 1342 kN
$=1.369\times(1050\times4)\times450$
$=2587$ kN > 1272 kN

Hence the depth is governed by one-way shear.

Provide overall depth of **D = 500** mm with 50 mm cover and use 20 mm diameter bars.

Effective depth, $d' = 500-50-20/2$
$= 440$ mm

which is approximately equal to the required depth (420 mm).

(x). Check for Base Pressure:

$q = (1200+1200)/(4.1\times2.95) + (24\times0.5) + (18\times0.55)$
$= 220.32$ kN/m^2 < 230 kN/m^2.

Design of longitudinal flexural reinforcement:

Maximum -ve moment:

$R = \dfrac{Mu^-}{Bd^2}$
$= \dfrac{977.8\times106}{2950\times450^2}$
$= 1.712$ MPa.

$\Rightarrow \dfrac{P_t}{100} = \dfrac{30}{2\times415}\times[1-\sqrt{1-(4.598\times1.71^2/30]}$

$\Rightarrow P_t = 0.51 > 0.3$

$\therefore A_{st}$ required $= 0.51\times2950\times600/1000$
$= 9027$ mm^2. $> 0.0012BD=1770$mm^2.

Hence provided 28 nos of 20mmϕ rods at 100 mm c/c at the top.

Development length, $L_d = 47\times20$
$= 940$ mm.

Adequate length is available on both sides.

Maximum +ve moment:

$R = \dfrac{Mu^+}{Bd^2}$
$= \dfrac{338.8\times10^6}{2950\times450^2}$
$= 0.567$ MPa.

$\Rightarrow \dfrac{P_t}{100} = \dfrac{30}{2\times415}\times[1-\sqrt{(1-(4.598\times0.567/30))}]$

$\Rightarrow P_t = 0.162$

A_{st} required $= 0.162\times2950\times600/100$
$= 2389.5$ mm^2

A_{st} min $= 0.0012\times2950\times600$
$= 1770$ mm^2.

Hence OK.

Provided 20 mm ϕ bars of 8nos at spacing 120 mm c/c at the bottom.

Transverse beams

Under column C1,

Factored load per unit length

$= 1600/2.95$
$= 542.37$ kN/m.

Projection of beam beyond column face

$= (2950-600)/2$
$= 1175$ mm.

Maximum moment at column face, Mu

$= 542.37\times1.175^2/2$
$= 374.4$ kNm.

Effective depth for transverse beam (20 mm ϕ placed above 20 mm ϕ rods),

$d' = 500-50-20 \times 1.5$
$= 420$ mm.

Width of beam = Width of column + 0.75d
$= 600+0.75 \times 420$
$= 915$ mm.

$$R = \frac{Mu}{Bd^2} = \frac{374.4 \times 10^6}{915 \times 420^2} = 2.31 \text{ MPa.}$$

$$P_t = \frac{30 \times 100}{2 \times 415}[1-\sqrt{(1-4.595 \times 2.31/30)}]$$

$= 0.709$

A_{st} required $=0.709 \times 2950 \times 600/100$
$= 1254.93$ mm^2

$\therefore$ Provided 6 nos of 20 mm ϕ bars at 100 mm c/c at the base of column C_1.

Under column C_2,

As the loading, column size are all same, provide the same reinforcement as of column C_1.

Transfer of force at column base:

Limiting Bearing stress at

i) Column face $= 0.45 f_{ck}$
$= 0.45 \times 30$
$= 13.5$ MPa.

ii) Footing face $= 0.45 f_{ck}\sqrt{(A_1/A_2)}$
$=0.45 \times 30 \times \sqrt{(2950^2/600^2)}$
but A_1/A_2 limited to 2.0
$= 0.45 \times 30 \times 2$
$= 27$ MPa.

Limiting Bearing Resistance at column-footing interface, F_{br}
$= 13.5 \times 600^2$
$= 4860 \text{ kN} > P_{u1}=P_{u2}$
Hence OK.

Hence minimum reinforcement dowel rods of 4 nos of 20 mm ϕ is provided.

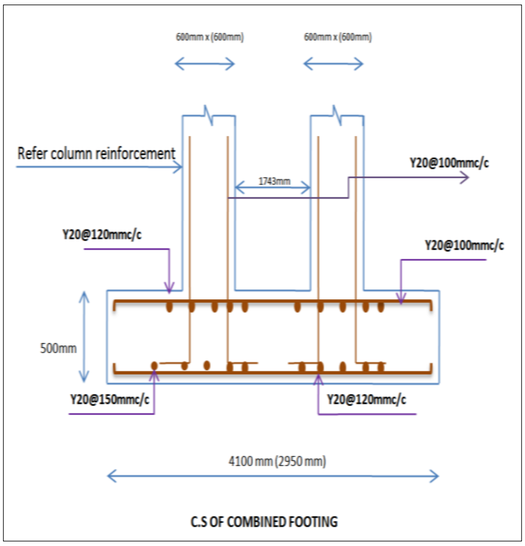

Fig. 9 Footing details

(d) Base plate design

As the base plate is placed at every 1m on the span of the beam, it may not be bearing any load transferring from the rail. So, minimum thickness of base plate suitable for holding the rail can be provided. In this case, a square plate of 300 mm x 300 mm x 16mm thickness is used.

(e) Anchor bolt design

Anchor bolts are designed to hold the base plate with the beams to hold the track in place. These bolts are placed at the time of casting of concrete. A standard bolt of size 16 mm diameter and 250 mm anchoring length is used. A number of 4 anchoring bolts on each base plate is provided.

V. CONCLUSION

From this study, it is justified that

- Less use of skilled labour,
- Optimal use of resources like ballast, sub-grade and grade formation,
- Less time consumption,
- Structurally stable track is obtained and
- Economical structure obtained using analysis software.

Thus, these results show that it can be adopted well in the case of shorter span track formations and further analysis can be done to achieve cost-cutting when compared to conventional method of track formation (ballast track).

VI.REFERNCES

[1]. M. Madhkhan, M. Entezam, M.E. Torki, Sharif University of Technology, “Mechanical properties of precast reinforced concrete slab tracks on non-ballasted foundations” in Scientia Iranica A(2012) 19(1), 20-26.

[2] Konstantinos Giannakos, Spyridon Tsoukantas, “Transition Zone between Ballastless and Ballasted Track: Influence of Changing stiffness on acting forces” in Social and Behavioral Sciences 48(2012) 3548-3557.

[3] L. Dieleman; M. Fumey; A. Robinet; Ramondenc; D. Martin, “ Experimentation of a track section without ballast on the new line of EAST EUROPEAN TGV” Science direct.

[4] Shengyang Zhu, Chengbiao Cai, “Stress Intensity Factors (SIF) evaluation for through-transverse crack in slab track system under vehicle dynamic load” in Engineering Failure Analysis 46 (2014) 219–237.

[5] IS 456:2000, code of practise for plain and reinforced Concrete.

[6] SP:16, Design aids for reinforced concrete to IS 456:2000.

[7] IS 800: 2007, General construction in steel.