Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 7; April-June, 2015 pp. 603-606

http://www.krishisanskriti.org/jceet.html

Study on Behaviour of Composite Sleepers

Rajendran R[1] and Tensing D[2]

[1]PG Student, School Of Civil Engineering Karunya University
[2]School Of Civil Engineering Karunya University
E-mail: [1]rajendranraja@gmail.com, [2]dtensing@karunya.edu

Abstract—*Railway sleepers have important roles in the complex railway system. Due to different loading condition, poor maintenance of sleeper or bad quality of ballast, a random load distribution along the sleeper-ballast interface may occur. A sleeper design, and also the track system design, which do not consider the random load distribution, could influence the performance of the sleeper and even damage the whole railway system. Results of suitable materials for replacing regular railway sleepers materials, vertical displacement of rail seat, stress at midpoint and underneath rail seat are presented. Moreover, the safe moment condition is also identified.*

Keywords: *Railway sleeper, sleepers design, material property, manufacturing process, testing method*

1. INTRODUCTION

Sleepers

Member which are laid transverse to the track alignment to support the rail and to transfer the load to underlying ballast from rail, are called sleepers.

Functions Of Sleepers

In a rail track, sleepers perform the following functions

1. To hold the rail in proper gauge in all situations (ie) exact gauge along straight and flat curves, slightly loose on sharp curves and slightly tight in dimond crossing
2. To support the rail firmly and evenly throughout.
3. To distribute the load transmitted through rails over large area of ballast underneath or to the bridge girders as the case may be.
4. To hold the rail proper level in turnout and crossovers, and at 1 in 20 in ward slop along straight track.
5. To provide the general stability of the permanent way throughout.

Requirement Of Ideal Sleepers

An ideal sleeper should meet the following requirements:

1. The initial cost and the maintenance cost of the sleepers should be low.
2. The fitting required for fixing the rails on to the sleepers, should be simple which can easily adjusted during the maintenance.
3. The crushing strength of the sleepers should be more with moderate weight.
4. They should provide sufficient bearing area to hold the rails seats and for the ballast to be supported on to resist the crushing due to moment of heavy axle load.

2. PROPERTIES OF MATERIALS:

Concrete Material

The railway sleeper is made of concrete material. The typical properties of normal strength concrete C55/67 used as input data:
Density: ρc=2400 kg / m3
Young’s modulus: Ec=30200 MPa
Poisson’s ratio: νc=0.2
Compressive strength: σcc=52 MPa
Tensile strength: σct=2.85 MPa
Fracture energy: GF=154 N / m

Pre-Stressing Reinforcement Material

Prestressed reinforcement in sleeper which can increase tensile capacity of the sleeper is also of importance. Typical properties of reinforcement are indicated below:
Density: ρs=7.8 g / cm3
Young’s modulus: Es=200 GPa
Poisson’s ratio: νs=0.3
Thermal expansion: α=1.1 * 10-5 / oC

3. DESIGN OF PRESTRESSED CONCRETE SLEEPER

Concrete sleeper has been used in some countries for more than fifty years. Sleeper is used to maintain rail gauge and rail inclination, as well as transmit loading and reduce ballast pressure. After World War II, in order to carry higher axle load and sustain higher speed, prestressed concrete sleeper started to be introduced and is now widely used especially in Europe and Asia. The use of prestressed 60MPa concrete ensures that sleepers are able to withstand variable loading conditions. Moreover, small cracks which can appear through accidental damage close automatically, preventing the degradation of the reinforcing steel and any damage to the integrity of the sleepers, Infraset (2009). In this thesis, sleeper of type A9P is studied, and detailed dimensions are shown below.

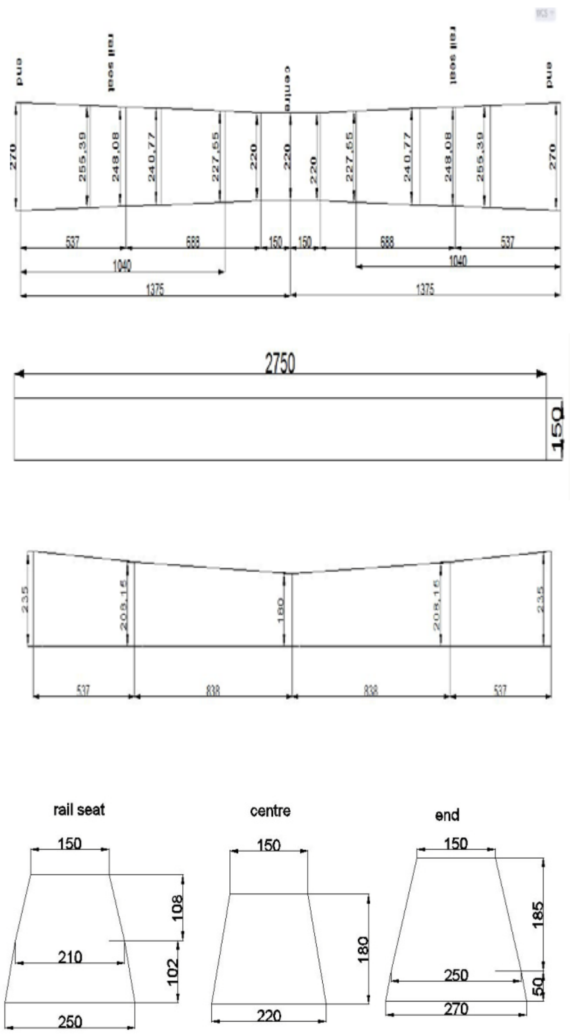

Fig. Sketch of sleeper Stress check at transfer At rail seat:

Stress at transfer at top rail seat
= (pi/Acr) - ($p_i e_{pr}/z_{tr}$)=10.00 MPa

Stress at transfer at bottom of rail seat

= (Pi/Acr) + (Pi e_{pr} /z_{br})=15.56 MPa (compression)

At centre of sleepers

Stress at service at top of rail seat

= (P_i/A_{cr}) - ($P_e e_{pr}/z_{tr}$) + ($M_{LL,r}/z_{tr}$)=20.02 MPa (compression)
Since 20.02 MPa is less than 0.4 f_{ck}= 22 MPa, it is safe

Stress at service at bottom of rail seat

= (P_i/A_{cr}) - ($P_e e_{pr}/z_{br}$) + ($M_{LL,r}/z_{br}$)=0.04 MPa (tension)

Since 0.04 MPa is less than 0.04 $f_{ck=}$- 2.2 MPa, it is safe.

Stress at service at top of centre of sleeper

= (P_i/A_{cc}) - ($P_e e_{pr}/z_{tc}$) + ($M_{LL,r}/z_{tc}$)=5.92 MPa (compression)
Since 5.61 MPa is less than 0.4 f_{ck}= 22 MPa, it is safe

Stress at service at bottom of centre of sleeper

= P_e /A_{cc} + P_e e_{pc} / Z_{bc} + $M_{LL,c}$ / Z_{bc}= 16.55 MPa

Since 16.31 MPa is less than 0.4 fck(= 22MPa), it is safe

Calculation of Cracking moment based on modulus of rupture

At rail seat bottom, Cracking moment $M_{cr\ is}$ given by,

-0.04 fck=P_e / A_{cr} + $P_e e_{pr}/Z_{br}$ - M_{cr}/Z_{br}=25.16 kN-m

At centre of sleeper top, cracking moment M_{cr} is given by,

-0.04 fck=P_e / A_{cr} + $P_e e_{pr}/Z_{br}$ - M_{cr}/Z_{br}= 17.19 kN-m

Factor of safety at rail seat bottom= $M_{cr}/M_{LL,r=}$25.16 / 17.03=1.48 (unsafe)

Factor of safety at centre top=$M_{cr}/M_{LL,c=}$17.19 / 6.85=2.51 (safe)

Ultimate Strength Calculation
At Rail seat
The stain variation in different layers of strands at decomposition and ultimate and strain variation in concrete at ultimate shown in fig.8. the corresponding forces in both prestressing strands is given in fig.9.

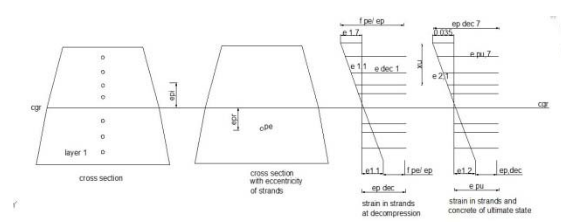

Fig. 4.8: Strain diagrams ultimate

Procedure for estimating ultimate moment capacity

Step 1: assume an initial values for neutral axis (N.A) depth x_u
Step 2: Find $\in_{pu,I}$=$\in_{p,dec\ I}$ +- $\in_{2,I}$ .... (Eq.1)
Where $\in_{pu,I=}$strain in strands at i th layer, at ultimate
$\in_{p,dec,I=}$strain in strands at i th layer, at depression stage
$\in_{p,dec,I=}$$f_{pe}$ / E_p +- $\sum_{l,i}$
$\in_{,I=}$+ ve if I th layer , at decompression stage
$\in_{l,i}$=P_e/A_{cr} +- $P_e e_{pr} e_{pi}/I_r$
$\in_{pi=}$+ ve if eccentricity of strands in i th layer is below C_{gr}
$\in_{p,,dec,I=}$$f_{pe}$ / E_p +-P_e/A_{cr} +- $P_e e_{pr} e_{pi}/I_r$
$\in_{2,I=}$0.0035e_{pci}/x_u, + ve if I th layer is below N.A at ultimate
$e_{pci=}$distance of d i th layer from N.A

Step 3: Find $f_{pu.i}$ corresponding to $\in_{pu.i}$ from fig.10
Step 4: Find $c_{0=}C_1 + C_2$
And $T_{u=}\sum^7_{i=1} f_{pu,i}A_{p,i}$
Step 5: if $\lvert C_u - T_u \rvert$ exceeds the acceptable tolerance (say, 1 kN), revise value
Of x_u and repeat steps 2-5. Otherwise, accept the values of
T_u=C_u and x_u, and proceed to step 6.
Step 6: find the ultimate moment capacity $M_{ur,}$ given by,

$$M_{ur=}C_1e_{c2} + C_2ec_2 + (\sum^7_{i=1} f_{pu,i}A_{p,i})$$

Where,
e_{c1}= distance from C_1 from N.A
e_{c2}= distance from C_2 from N.A
the ultimate moment capacity of sleeper at rail seat and center of sleeper is calculated base on this stain compatibility method and given in table 1 and table 2 respectively.
Assume X_u= 92.8mm
Ultimate moment capacity at rail seat M_{ur}= 42.68 kN-m
Maximum moment acting at rail seat due to live loadd, $M_{LL,r}$=17.03 kN-m
Load factor at rail seat bottom=42.68/17.03=2.51
Assume X_u =73.12mm
Ultimate moment capacity at rail seat M_{ur}= 32.08 kN-m
Maximum moment acting at rail seat due to live loadd, $M_{LL,r}$=6.85 kN-m (hogging)
Load factor at rail seat bottom=32.07/6.85
= 4.68

Flexural capacity of sleeper

The American Railroad Engineering Association (AREA) design method was developed to calculate the required minimum flexural capacity of sleeper, in order to determine the maximum rail seat load based on elastic foundation beam model, see Doyle (1980). This method assumes a uniform contact pressure distribution between sleeper and ballast which produces positive flexure at rail seat and negative flexure in the middle of sleeper.

The rail seat load qr (KN) is expressed as

$$qr=Ps * DF * (1+ø)$$

where Ps=static wheel load (KN), DF=distribution factor, refer to Doyle (1980), ø=impact factor (assumed value for all conditions is 1.5).

Therefore the assumed uniformly distributed load W (KN/m) over the entire sleeper length l (m) is

$$W=2qr/l$$

The maximum positive sleeper bending moment at the rail seat Mr (KN m) is given by

$$Mr=w* (l-g)^2/8$$

where l=total sleeper length (m), g=distance between rail centres (m), W=assumed uniformly distributed load (KN / m).

The maximum negative sleeper bending moment at the centre of the sleeper Mc (KN m) is given by

where qr, l and g are as previously defined.

The required reinforcement can be further calculated due to bending moment, not in detail in this thesis. An example of diagrams of displacement, bending moment distribution and required reinforcement.

4. SLEEPER MODELLING AND VALIDATION

In this section, a finite element model (FEM) for sleeper is discussed. The model is established using Finite Element package – Abaqus, which is a numerical tool used to model and simulate the mechanics behaviour and response of sleeper. In this study, the sleeper is modelled as a three dimensional solid element, SOLID 65, while prestressed tendon is modelled as an embedded truss element, LINK 8, which is subjected to initial prestressed force. Bond slip between concrete and reinforcement is ignored. Cross section of the sleeper is simplified as rectangle. The non-linear material inputs have been given in the previous chapter.

Static modelling of sleeper with fixed support

At first, a simple static sleeper model with fixed support condition is modelled, analysed and compared with Rikard (2000), see figure 4. This part of the work is used to make assessment the quality of FE model and validate the model with respect to existing ones.

Modelling of sleeper

As the validation step, a sleeper is subjected to the same hydraulic jack loading as Rikard (2000), see section 2.1. This loading makes the sleeper deflect at a constant velocity of 0.05 mm/min. Hydraulic jack is applied to a rigid steel plate which locates just above the surface of rail seat, which closes to the real situation in the static full-scale test, see figure 4. And the loading duration is about 1.5 hours. In addition, a uniformly distributed gravity is applied to the body of sleeper as well. The support condition is fixed both in vertical direction at four points of the bottom of the sleeper like those in the test, see figure 9. Furthermore, a friction in lateral direction applied along the bottom of the sleeper is modelled as the boundary condition in the model.

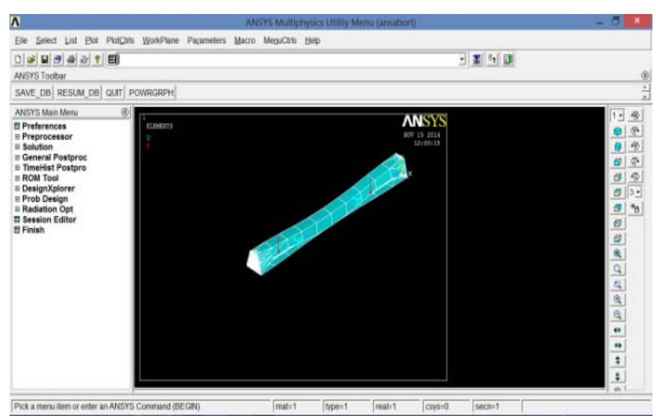

Fig: railway sleeper with simple support

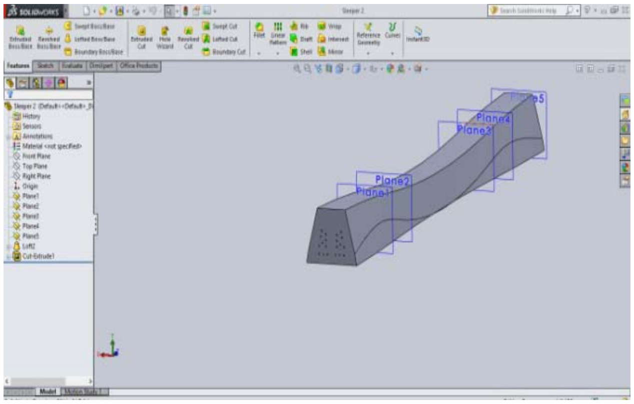

Fig. Embedded reinforcement placed into the concrete structure

Numerical results

In order to validate the quality of this FE model, its numerical results are compared with those from Rikard (2000), for example, the stress-strain relation for concrete and steel and load-vertical displacement diagram. The only difference to the model by Rikard (2000) is the non-linear behaviour of concrete material because of lack of input data. In this FEM model concrete is modelled as elastoplastic material, while in Rikard's model concrete is modelled as elastoplastic and brittle cracking material.

Stress-strain relation of reinforcement (solid line represents the FE result and dotted line represents the input data of steel)

Stress-strain of concrete (solid line represents FE result and dotted line represents result from Rikard (2000))

it is seen that the stress-strain relations between concrete and steel material from FE model are quite similar to the input data and the results by Rikard (2000). This is used as an assurance that the quality of this sleeper model looks good. In fact, after concrete reaches its ultimate compressive strength, the stress will start to decrease due to cracks occur, which can be defined as brittle cracking behaviour. Modelling of brittle cracking material is used to capture brittle cracks in sleeper, but because there are not sufficient input values for this kind of concrete non-linear behaviour, therefore in the following analysis, the duration time for applying hydraulic jack load is shorten from 1.5 hour to 1 hour to ensure that the compressive strength of concrete material will not decrease.

Force-displacement of underneath the rail seat (dotted line represents FEM result and solid line represents result from Rikard (2000))

It is clear from figure 14 that the force and vertical displacement diagram matches well to Rikard (2000), which proves again that the quality of FE model is good.

5. CONCLUSION

Stress

a. The final compressive stress calculated by using load per area relationship was found to less than the permissible stress specified UIC code.
b. The final tensile stress are found to be close at to zero where as the tensile stress as per UIC was permitted to the extent of 2.2 MPa.

Load factor

The load factor at rail seat bottom and at centre top was found to be close as per UIC value by using ultimate moment and maximum moment relationship.

factor of safety

The factor of safety at rail seat bottom and at centre top was found safe according to the value specified in UIC code.

Deflection

As per the code the allowable deflection should not exceed 20 mm that we have found as theoretical which is not more than 20 mm.

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