Capacity Analysis of Railway Concrete Sleeper

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Abstract

Railway is one of the most important reliable and widely used means of transportation and it convey freight, passengers, minerals, grain, etc and its infrastructure has been regaining their importance due to their efficiency and environmentally friendly technologies. This leads to increasing the train axel load, vehicle speed, track structure capacity and more frequent train usage. The demand for rail transport is derived with the possible exception of sight-seeing, people travel to satisfy another need at their destination and this increase the rail demand transportation. To accommodate the increase in rail demand, trac council council k structure is constructing a new railway line or improving the existing railroad structure. Upgrading the existing structure will increase its capacity and improving the existing structure more durable and reliable means of transportation. These improve the service provision to brought new challenge to the old railway track engineering. This challenge demanded for a better understanding of both static and dynamic response of track structure. Due to different loading condition, poor maintenance of the sleeper or poor quality of the ballast, unbalanced load distribution along the sleeper-ballast interference may occur. The Structural analysis of existing sleeper is carried out by using finite element method. The finite element analysis include dynamic and general static analysis. The parametric optimization of pre-stressed concrete sleeper is focused on increasing the capacity of the existing sleeper design through an investigation on pre-stress type, quantity, configuration, stress level and other materials properties. The study of parametric optimization indicate that increasing the existing sleeper capacity by changing the strand tendon diameter and compressive concrete strength.

Keywords: At transfer, at service, Jacking force, Pretension, Transfer length, Development length.

Introduction

Railway transportation is a means of freight and passengers, by means of wheeled vehicles running on track structure. In contrast to highway transport, where vehicles merely run on a prepared surface, rail vehicles are also directionally supported by the tracks on which they run. Railway track structure usually consists of rails installed on sleepers and ballast, on which the rolling stock, usually fitted with metal wheels, moves. However, other track type variations are also possible, such as ballasteless track where the rails are fastened to a concrete foundation resting on a prepared subsurface.

Different countries over the world invest large amount of money to adopt and research on sleeper design, construction and maintenance because of its sensitivity for any kind of mistake by responding badly. Therefore, it's necessary to research on better, up to date and relevant design philosophy should have to be followed. This has the significance in adopting design guide rules of sleeper for countries struggling to adopt design code like Ethiopian, improving some design guidelines for countries already adopted like China and advancing technologies that can ease construction and reduces maintenance load and frequencies of ballasted track sleeper. Amongst many sleeper types the widely used Mono-block Prestressed concrete sleeper type is targeted.

The research was anticipated that the suggested method of increasing the sleeper capacity and will aid the proposed transition to higher tonnage application. The out put of this thesis will benefit for both prestressed concrete sleeper manufacture and the heavy haul railroad class.

Research significance

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1.2. Research Objectives

The major objectives of this paper is to help the railway track owners to increase the efficiency of the railway sleeper through the improved knowledge for track behavior under wheel load and develop realistic process of analysis for the design of railway sleeper.

- ✓ Establish a probabilistic based assessment methodology for railway track.
- ✓ Develop realistic design approach for prestressed concrete sleeper.
- ✓ Develop the final design which will be capable of withstanding the anticipated load of heavy haul railway.
- ✓ Prepare this paper as a source of document for prestressed concrete sleeper design which will optimize the railway sleeper design parameter.

1.3. Research Scope

- ✓ Increasing the existing capacity of prestressed concrete sleeper,
- ✓ Analyze the static and dynamic behaviour of the existing sleeper,
- ✓ Examine the baseline sleeper design capacity by analyzing the existing the prestressed concrete sleeper design.
- ✓ Selection of appropriate model of railway sleeper behavior.

1.4. Statement of the problem

Although there are numerous publication dealt with the design of railway track , it is clear that the are several issue that have not been solved yet with the problem of insufficient design of both static and dynamic loading that the railway track is subjected to its life time and the capacity of the track structure is not known. This thesis is measuring various static loading regimes is that the risk related with the various operation are all different. The dynamic load profile is heavily depending on the characteristics of the vehicle setup.

1.5. Research Methodology

To extract further performance out of the track, a more realistic assessment of the loading scenarios is needed to determine the limit of railway sleeper capacity. The research aims to make the assessment the railway sleeper based on probabilistic loading scenarios by establishing appropriate design methodology for railway sleeper. While analyzing both static and dynamic load effects are considered, in which strong and reasonable factors consideration is required.

2. Modeling of prestressed concrete sleeper

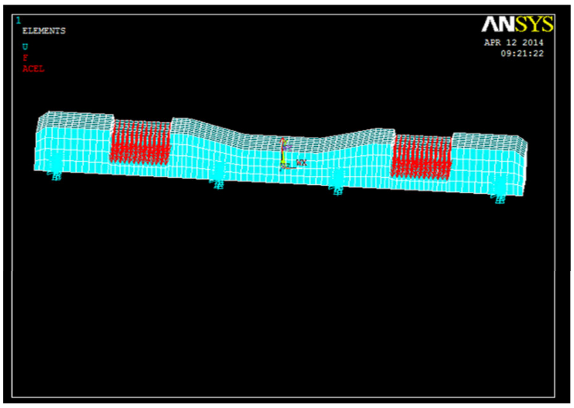
In this section , a finite element model for sleeper is discussed. This model is established using finite element package ANSYS, which is numerical tools used to model and simulate the mechanics behaviour and response of the sleeper. In this study the sleeper is modeled as a three dimensional solid element, SOLID 65, while the prestressed tendons is modeled as an embedded truss element.

2.2.1. Static modeling of sleeper

The aim of this section is to assess the quality of finite element method and numerical results regarding structural behaviour of sleeper will not be analyzed in detail because of the fixed support condition occurs rarely. However , the further analysis using this finite element model can be processed on the next section. The static analysis not enough and the most severe damage mainly come from dynamic loading, dynamic model of the sleeper is studied in order to get a reliable response for sleeper analysis, such as critical displacement and stress distribution.

2.2.2. Dynamic modeling of sleeper

Much server damage is occur due to dynamic load where its magnitude, direction or position varies with time applied to the sleeper instead of static loads; as a result dynamic analysis is vital. In order to study the dynamic behaviour of sleeper, modal supper position procedure will be carried out, this procedure mainly applied to linear dynamic analysis, using through ANSYS and the foundation of this method is eigenmode of structure. This analysis is suitable for calculating linear problem on dynamic structural response in time domain, for instance time varying deflection and stresses. Firstly a frequency extraction should be defined; secondly the dynamic characteristics of the sleeper can be obtained, such as natural frequency and mode shape; finally harmonic dynamic analysis can be achieved.



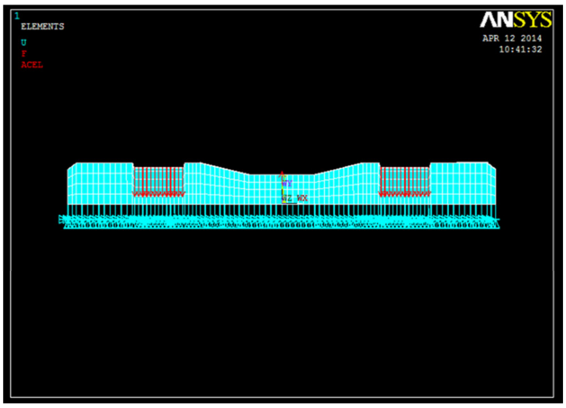


Fig 1. Static modeling of sleeper with fixed support   Fig 2. Uniform interaction between sleeper and ballast

In this dynamic analysis, the sleeper is modeled as solid element as previous static model. But the main important point is considering the sleeper model is supported by a viscous damper, massless elastic foundation with certain stiffness that simulated the simplified underlying ballast support which allow the sleeper move up and down, see the figure below. Non linear concrete behaviour is not taken into account, as well as the possible crack condition. Furthermore, for the sleeper and ballast interaction, instead of fixed support, discrete spring stiffness of 7.5MN/m^2 are connected the ground with at the interval of 70 mm. This roughness approximation is good enough because what are connected with only the peak values and ballpark variation from ANSYS output. The boundary condition is the constant friction at the bottom interference of the sleeper. To simplify the dynamic modeling a dynamic loading is introduced, when assume a single dynamic loading wave pass on a single sleeper with the speed of 120Km/hr and with no irregularity of the rail or wheel profile.

There are two numerical results which can be obtained from nodal supper position analysis is presented in the following two section. First natural frequency extraction is discussed and is followed by the important dynamic structural response, like vertical displacement and reaction force are plotted from transient modal analysis. Engevalue extracted is performed to calculate the natural frequencies and the corresponding mode shapes of the sleeper.

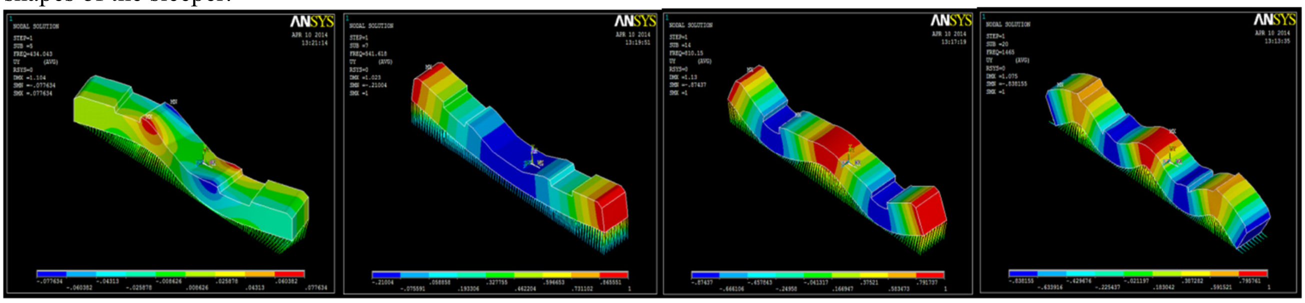
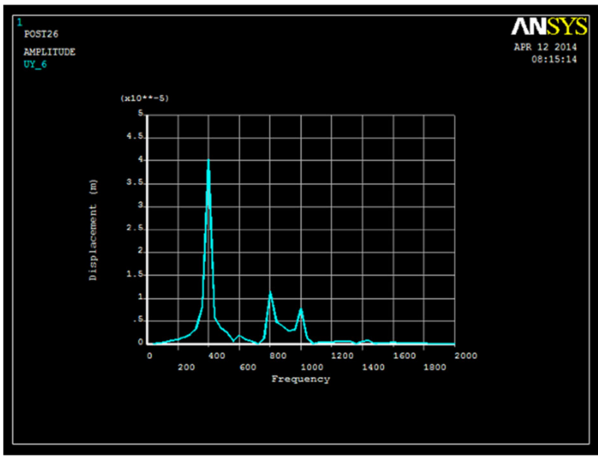


Figure 3. Mode shapes on sleeper No 1, 7, 14, 20.

3. Reaction force and vertical displacement

Dynamic analysis is carried out on a single sleeper. The numerical results of dynamic structural response are considered as the reaction force of the sleeper and vertical displacement at the rail seat. The reaction force of the sleeper can be calculated as spring stiffness multiplies vertical displacement for the positions where there are spring element underlying and the vertical displacement at the rail seat can be plotted from ANSYS.



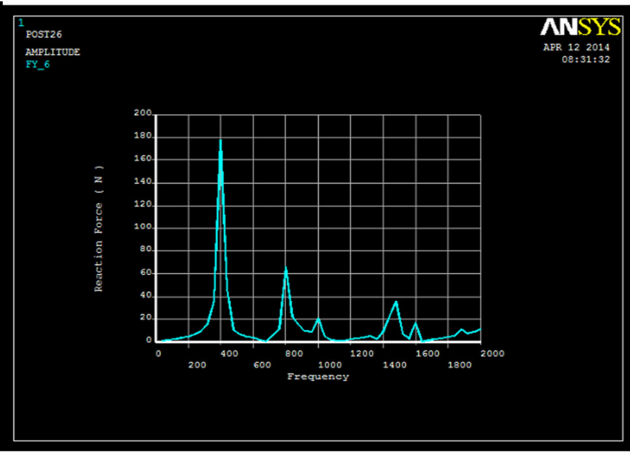


Figure 4. Vertical displacement at rail seat

Figure 5. Reaction force of sleeper

3.1.1. Prestressed losses

The losses that occur due to the prestressing can be characterized into two group; instantaneous loss and time-dependent loss. Instantaneous losses include anchorage set, friction and elastic shortening and the loss due to time-dependent include creep, shrinkage of concrete and relaxation of steel.

3.1.2. Concrete strength at transfer

This is when the concrete first feel the prestress. The concrete is less strong but the situation is temporary and the stress are only due to prestress and self weight. During the fabrication process of sleepers there are two loading conditions are considered for evaluation of the concrete stress at the transfer; In first case, the sleeper is upside down in the form and in second case, the sleeper is the right side up.

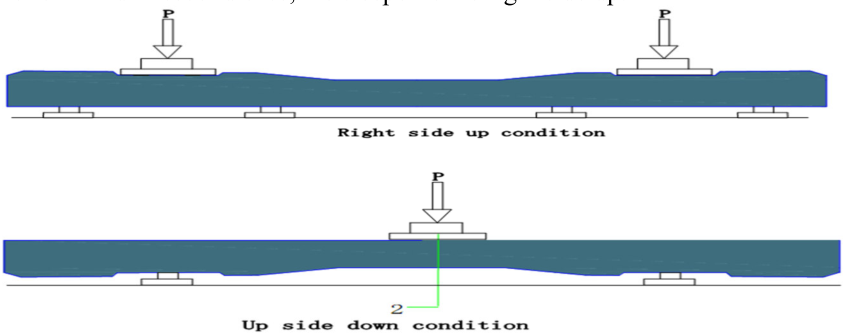


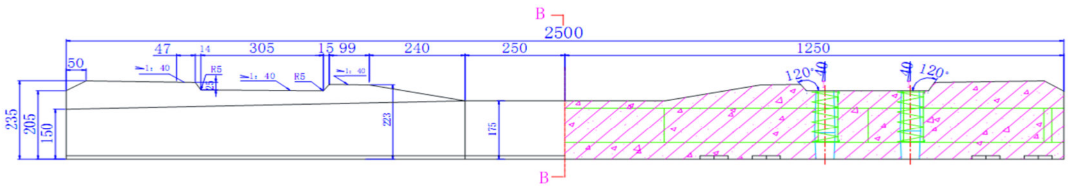
Figure 6. The Loading conditions and distance from the end of the sleeper to the critical section

The stress in the concrete immediately after prestress transfer shall not exceed the following criteria;

- ✓ The extreme fiber stress in compression at is equals to ………………0.6 f'_c
- ✓ The extreme fiber stress in tension expected as permitted in ……..$3\sqrt{f'_c}$

4. Numerical analysis of sleeper capacity

When the behavior of the railway sleeper has been analyzed , the next step is to optimize it. Optimization of mechanical structure generally mean improving the sleeper performance during the working cycle under some manufacturing, operational and failure condition as well as cost limitations. In the traditional design of such structure the optimization is carried out in primitive way by modification of separated design parameters and repeated numerical analysis.



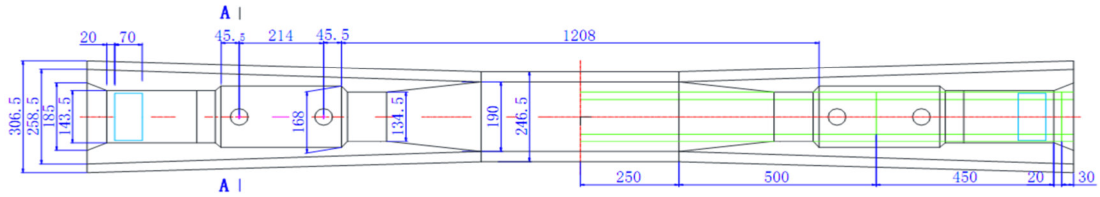


Figure 6. Cross section of Chinese sleeper (Type II)

The total time dependent prestressing losses between jacking and effective prestressing at 28 days and 50 years at the rail seat and center section are summarized in table 4.3.4.1 and 4.3.4.2. The actual prestress loss occurred at the center are larger than the rail seat due to the decrease cross sectional areal to resist the same prestressing force. The smaller cross sectional area of the center section increase the stress in the concrete due to the prestressing and in turn increase elastic shortening, creep and shrinkage losses which are a function of stress in the concrete.

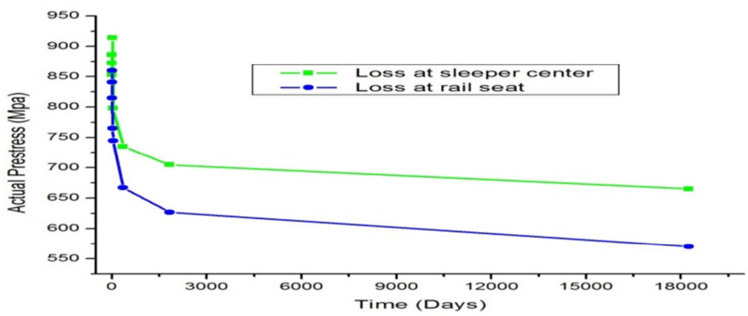


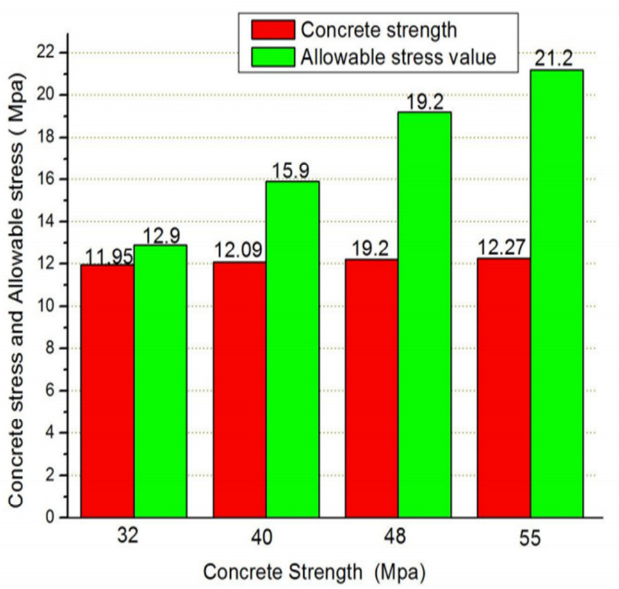
Figure 7. Actual prestress losses at transfer and service

4.1. Limit State Design

Using the value for initial and final effective prestressing in table 4.34.3, the base line sleeper was evaluated for the limit state of concrete stress at transfer and concrete stress at service. The allowable concrete stress limits served as the boundary for these limit states.

4.1.1. Limit state for Concrete stress at transfer

For Prestressed concrete stress at transfer, two load configurations were evaluated which relates to the orientation of the sleeper during the manufacturing process. In the first configuration the sleeper takes almost immediately after transfer when the sleeper is de-modeled and rotated right side up. In the second condition the sleeper is up-side down in the form at the instant of prestressing transfer. The main reason for considering both loading condition is the short time frame following transfer in which they both occur.



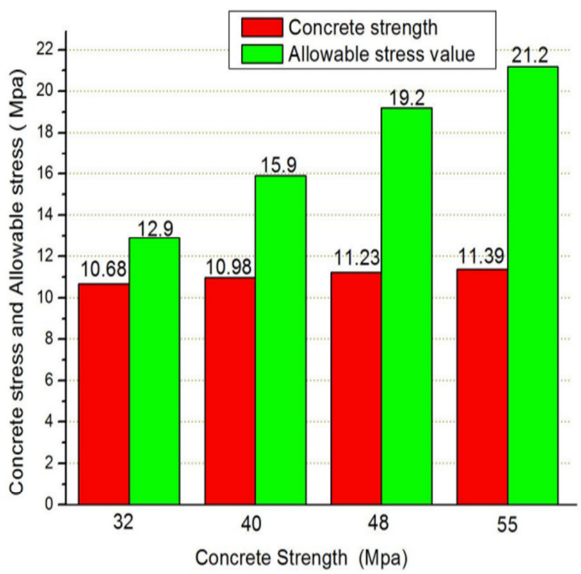
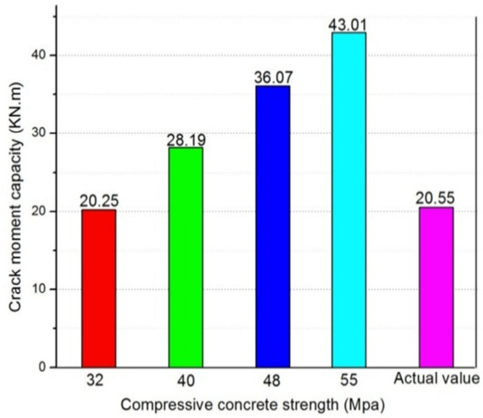


Figure 8. Concrete stress at transfer at railseat   Figure 9. Concrete stress at transfer due to self weight at center

The entire sleeper remain in compression at transfer with the large stress in the top of the sleeper at the rail seat section and in the bottom at the center section. The stress in the concrete at the transfer due to prestressing and self weight for both loading condition were with in allowable concrete stress specified by a minimum concrete strength of 32 Mpa. The applied stress are with in allowable limit, the stress in the top of rail seat section of sleeper approaches the compressive limit, when the self weight and prestressing cause bending in the same direction.

4.1.2. Limit state for concrete stress at service

The stress induced by the self weight and live loading , in addition to the prestress and self weight must be checked. At service stage , the concrete has full strength but losses will have occur and so the prestress force is reduced. The live load due to the moving train load is unknown and was solved by setting the applied stress equals to the allowable concrete stress . The self weight moment at the rail seat and at the center of sleeper section are based on the boundary conditions of the test. Comparing the minimum calculated live load moment to the self weight moment it was determined that the moment due to the self weight



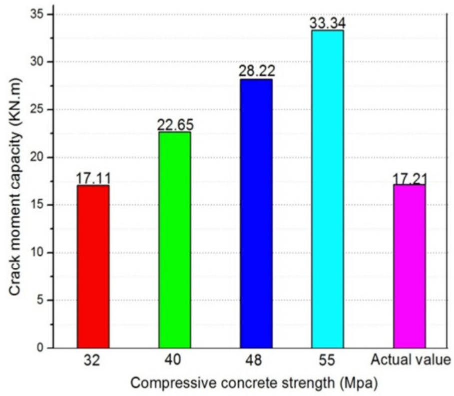
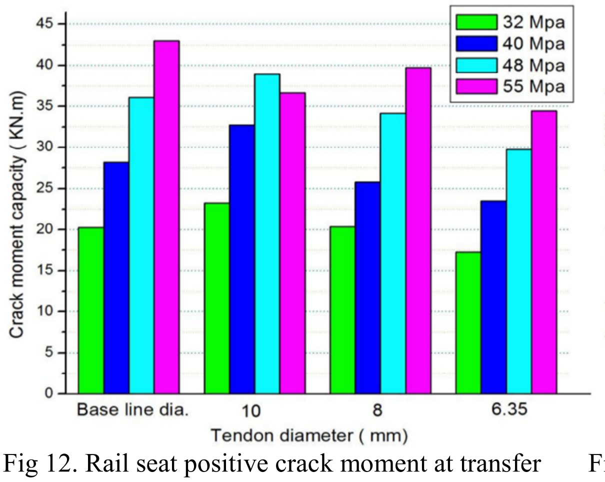


Fig 10. Rail seat (+)moment with concrete strength Fig 11. Sleeper center (-)moment with concrete strength

4.1.3. Comparisons of the theoretical flexural capacity with the experimental flexural capacity.

The comparison of the calculated crack flexural capacity correspond to the limit state of the concrete stress at service are compared to the design value of the sleeper. The design value that specified by the sleeper factory only include the capacity for the governing bending condition. The flexural capacity based on the theoretical and sleeper factory result is presented in the table below. The flexural capacities are based on the prestressing force at 28 days and it should be predicted that the flexural capacity of sleeper will decrease over the service life time.



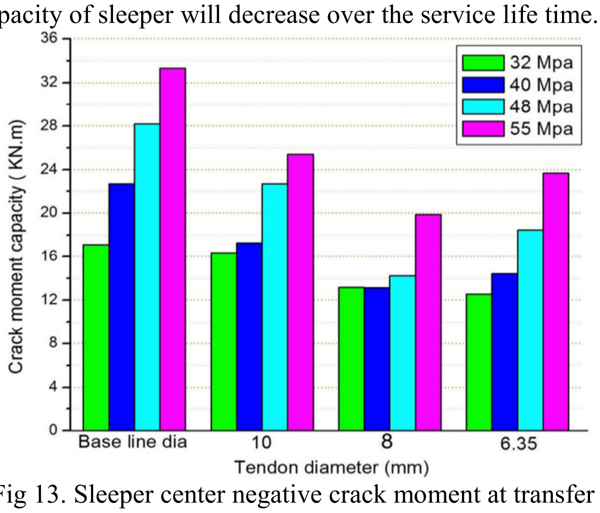


Fig 12. Rail seat positive crack moment at transfer Fig 13. Sleeper center negative crack moment at transfer

4.1.4. Development and transfer length

The prestresing tendon provide the bond between the concrete prestressing tendon up to the stress level associated with the nominal capacity of sleeper. If the tendons are not able to provide the necessary level of stress with the provided anchorage, the tendons become pull out of the concrete before it reaches the ultimate capacity. The distance required to provide the necessary bond between the concrete and the prestressing tendon is known as development length.

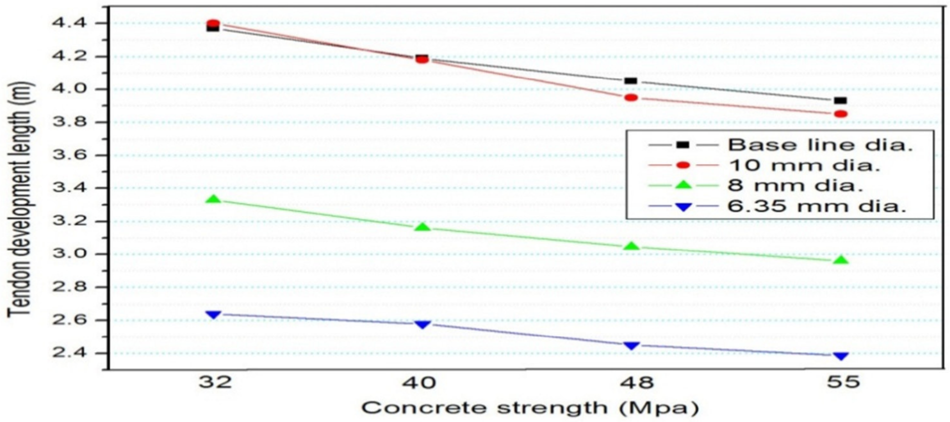


Fig 14. Development length of different prestressing tendon with concrete strength

5. Parametric Optimization Analysis

The parametric optimization analysis is used to determine the sleeper design components such as the prestressing type , concrete compressive strength and configuration that offer the efficient uses of material. In the analysis procedure, large quantity of data were gather during the optimization study an iteration matrix is done to arrange the collected data for the design iteration and the corresponding values of each calculation analysis. The first step in the optimization analysis is creating nomenclature system based on the design parameter which are used for both naming of calculation parts.

5.1. Prestressing area

The concrete compressive strength increase, the area of prestressing tendon in the sleeper section will increase to resist the application heavy load from prestressing force. The prestressing strand wires are already tensioned to their allowable stress limit , the only way is increasing load was add more strand wire to the sleeper section. The quantity of tendons in the sleeper section is limited by the detail requirement of concrete cover and tendon spacing.

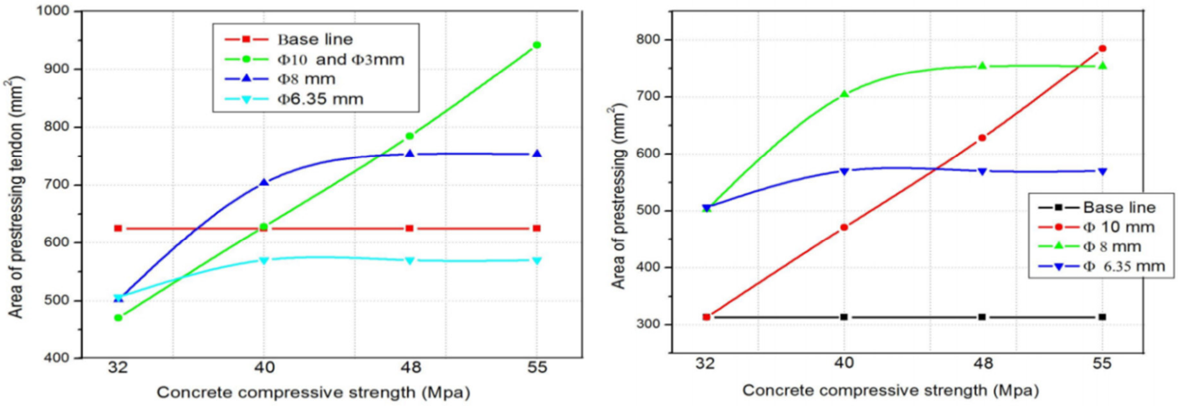


Fig 17. Area of prestressing tendons for positive rail seat and negative sleeper center

5.2. Limit stress at service

The same limit state discussed for baseline sleeper optimization study but the concrete stress at is some what inconsequential since all iterations were designed with the intension of achieving the maximum allowable stress in the concrete at transfer in order to have full capacity in terms of the material used and the large possible moment capacity for the governing load case of the iteration.

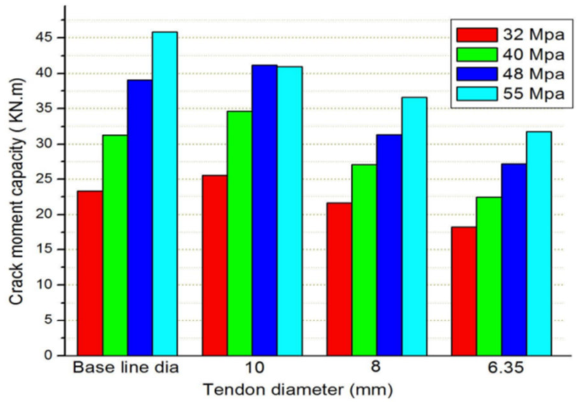


Fig 20. Rail seat (+) moment capacity at service

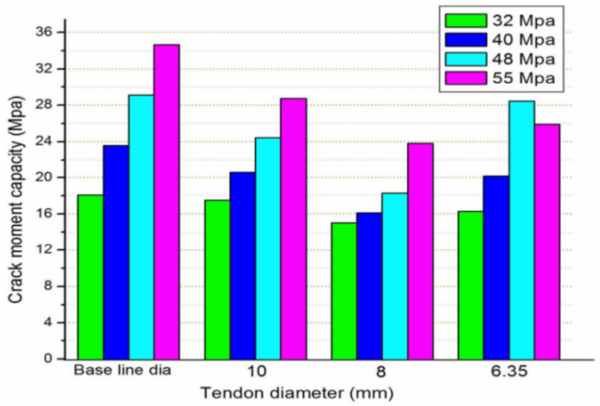


Fig 21. Sleeper center (-) moment capacity at service

6. CONCLUSIN AND RECOMMENDTION

6.1. Conclusion

The traditional railway track design uses an allowable design approach, with economic consideration frequently dictating component selection and size. The railway track in reality is a complex non linear system, which is characteristic that the current design procedure typically ignored. The Chinese railway standard for track design commented that when designing individual components it would be desirable to consider the track component together as static and dynamic system. Therefore there is a need to evolve the current Chinese railway design code from the allowable principle to amore realistic design philosophy.

The analysis and design practice for improving the railway sleeper is entirely based on satisfying several criteria for the strength of the individual component. Due to the variation of track support capacity in rail, the design loading determined by the theoretical and empirical relationships are arbitrarily increase by what are considered reasonable safety factor. Having determined the maximum deflection and bending stress in the individual track component of the track structure, they are then compared with the corresponding maximum allowable stress and if satisfied, the design is completed.

6.2. Recommendation

The recommendation presented in this thesis is developing the methodology for increasing the capacity of the existing prestressed concrete sleeper that concerned with the associated cost, the economy that needed to modify the manufacturing process and long term capacity are expected to control the selected solution. The other point that warrant consideration includes durability, thermal and fatigue resistance beyond the standard limit state which has been exceeded in some environment .

For future the railway industry in Ethiopia will become more competitive with other mode of transport, there will be an increase commercial pressure to develop a more efficient and reliable transportation, it need upgrading the existing track structure and make them to economical and durable.

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