

# Fatigue Evaluation of Track Slabs Reinforced with Steel and CFRP Bars using Finite Element Analysis

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**ABSTRACT:** Traditional ballasted track has a disadvantage of heavy demand for maintenance. Drainage deficiencies and weakness of subgrade also leads to huge maintenance costs. This can be overcome by using slab track. In its simplest form, slab track consists of a continuous concrete slab with the rails supported directly on its upper surface using resilient pads. In this work, four track slabs are modelled, two slabs with steel reinforcements and other two slabs reinforced with CFRP bars. Also two types of rails are provided- bull headed rail and flat footed rail. High speed train pulses are applied to carry out transient analysis and fatigue analysis is done as the post processing of transient analysis. From fatigue results, damage and life of all the four slab structures are compared and thus slab structure with best fatigue performance is identified.

**KEYWORDS:** Fatigue, Slab Track, High Speed Train Pulse

## I. INTRODUCTION

A track or a permanent way is a structure consists of rails, fasteners, sleepers, ballast or slab track and underlying sub grade. It gives a dependable surface for wheels of trains to roll. Most railway tracks with heavy traffic use continuously welded rails, typically flat bottomed section, attached on sleepers by means of base plates that spread the load. A rubber or plastic pad is usually provided between rail and the base plate. The track ballast is generally crushed stones and the purpose of providing this is to support sleepers and allowing free drainage.

Steel bars of different grades and diameters are generally provided as reinforcements in slabs for many years. Its primary shortcoming is that it is easily be corroded, and this results in structural failure. Recently, there has been an interest in using non-corroding FRP rebars to overcome this issue of corrosion. In this study, Carbon Fiber Reinforced Polymer (CFRP) rebars and steel bars are used and their effects on fatigue are studied.

G. Ruiz, et al[3] modelled a slab track structure and conducted its fatigue study to find out its life and damage. J. Blanco-Lorenzo et al and C. Cai, S. Zhu[2] conducted dynamic analysis on slab track. Y. Yang, et al [8] evaluated the behaviour of a Basalt Fiber-Reinforced Polymer (BFRP) bar-reinforced ballastless track slab over steel reinforced one, subjected to a fatigue loading. There were no studies conducted on fatigue behaviour of carbon fiber reinforced polymer bar-reinforced slab tracks and hence my study was based on it.

In this paper, fatigue damage and life of slab tracks reinforced with steel and CFRP bars are compared. Also two different track profiles are provided. Fig 1(a) shows a typical track slab structure and fig 1(b) shows bull headed and flat footed rail cross sections. Slab track structure is modelled using ANSYS workbench 16.2. ANSYS is general purpose software, used in the case of physics, structural vibration, fluid dynamics, and heat transfer for engineers.

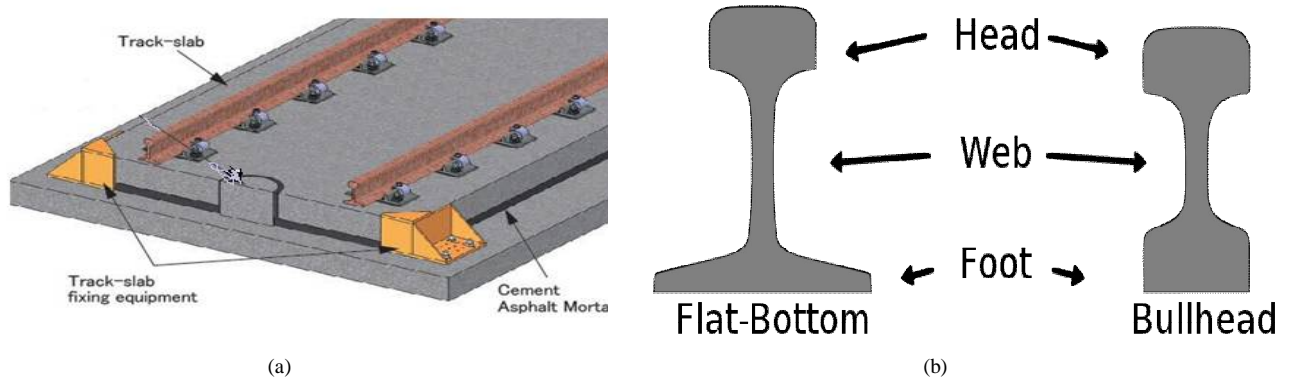


Figure 1: (a) Slab track structure and (b) Types of rail profiles

## II. VALIDATION

To identify the effectiveness of the adopted fatigue evaluation procedure, a validation process is essential. For validation, experimental test results provided in the journal “Fatigue life prediction of steel I-section using finite element simulation” are compared with results obtained from ANSYS Workbench 16.2.

Specimen was tested as simply supported beam with a span of 2800 mm. Two point loads of magnitude 100 kN each were applied on top flange using spreader beam at a distance of 250 mm from mid span of beam section.. Fig 2(a) shows the loading diagram and figure 2(b) shows the fatigue life of the steel beam in ANSYS.

The results from ANSYS FE model were compared against journal results. Comparison of fatigue results is shown in table 1. The fatigue life obtained from ANSYS is approximately equal to the journal values

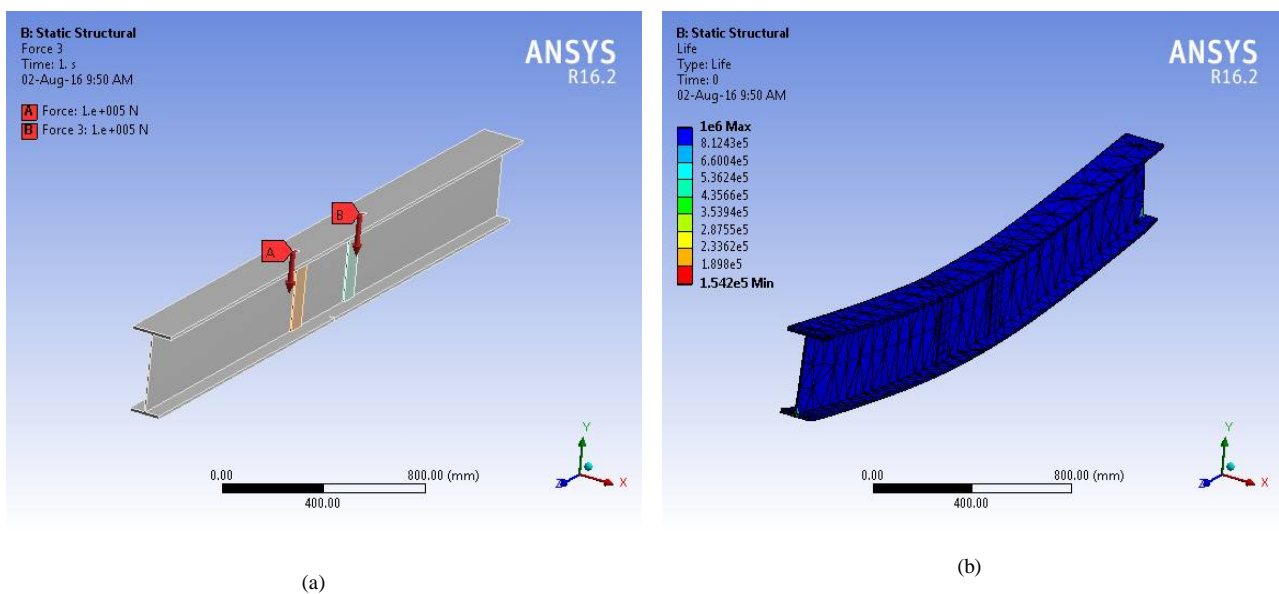


Fig 2: (a) Loading Conditions and (b) Fatigue life of the steel beam

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TABLE 1: Fatigue results for validation model

Sl no:	Method of Evaluation	Fatigue life ( cycles)
1	Experimental fatigue test	$15.6 \times 10^4$
2	Analysis using finite element tool ANSYS	$15.42 \times 10^4$

### III. FATIGUE EVALUATION OF TRACK SLABS REINFORCED WITH STEEL AND CFRP RODS

Due to track line symmetry (x-axis), half of the slab track geometry is represented. The slab track structure consists of concrete track slab, CA mortar layer, concrete roadbed, fastening cushions, soil subgrade and UIC 60 flat footed rail or bull headed rail and the length of the track structure considered is 7.15m. For modelling this structure, proper elements are selected from ANSYS element library. Fig 3 shows geometry in ANSYS and table 2 shows its dimensions.

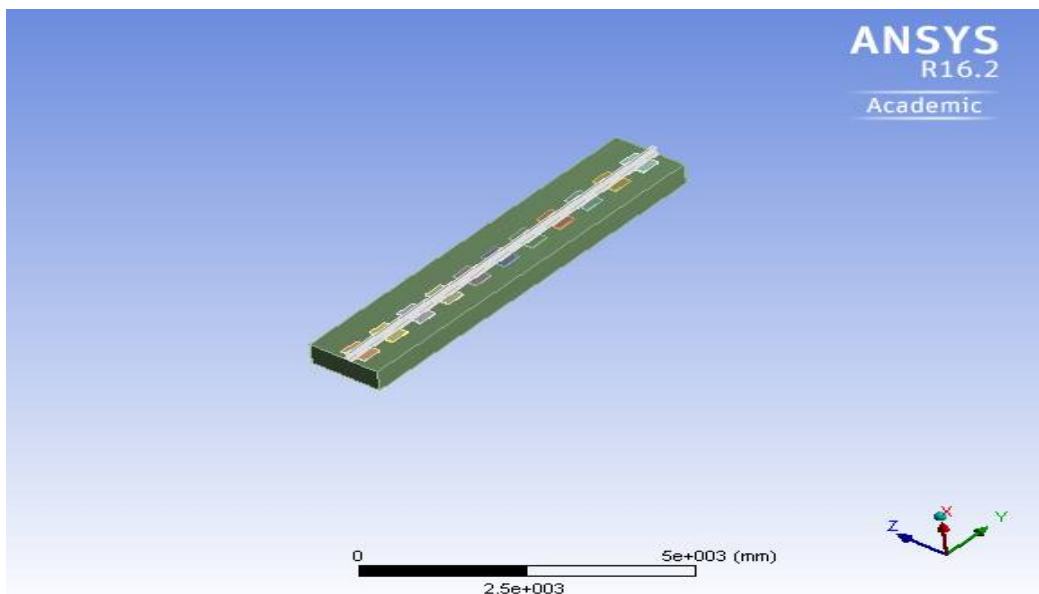


Fig 3: Geometry in ANSYS

Figure 4(a) and figure 4(b) shows flat footed and bull headed rail geometries created in ANSYS and its meshing. Flat footed rail has a wider foot portion while bull headed rails has less foot width area.

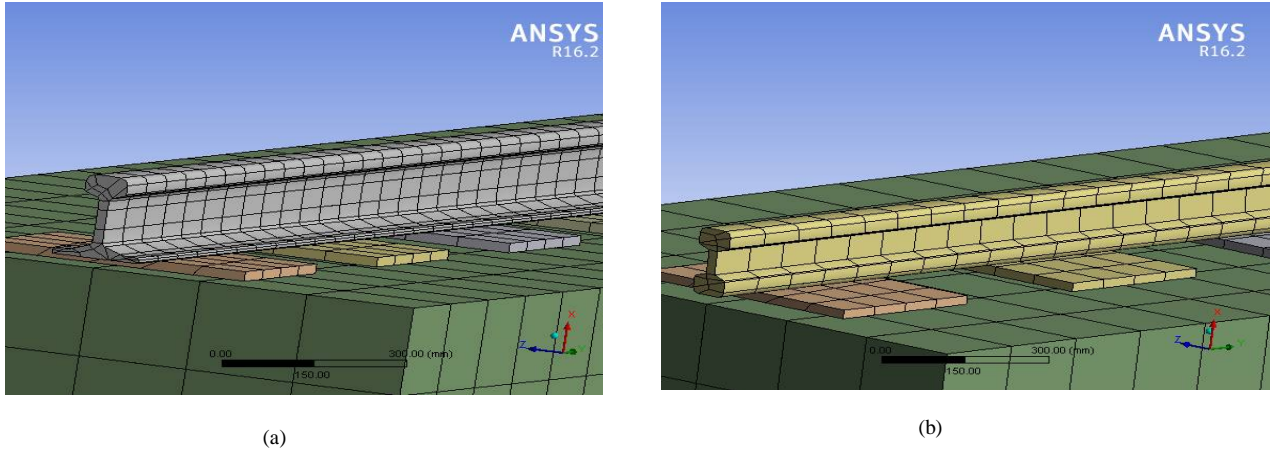


Fig 4: (a) Flat footed rail and (b) bull headed rail in ANSYS

TABLE 2: Vertical and transversal dimension of the FEM model

Layer	Vertical dimensions (z axis)(m)	Transversal dimensions (y axis)(m)
Slab track	0.55	1.3
CA mortar	0.10	1
Concrete roadbed	0.30	1.3
Fastening cushion	0.02	0.45

### 1. Boundary Conditions and meshing

After modeling slab track system, symmetry boundary conditions are imposed on its both ends. Such boundary conditions are also imposed equally on concrete road bed, concrete asphalt mortar layer and soil subgrade. Out of plane movements in soil subgrade are also restricted at two side surfaces parallel to the track line and at the bottom of the track. To reduce computational time, mesh size has been carefully designed. Table 3 shows the material properties of various component parts of the track structure [1].

TABLE 3: Material properties

	E (GPa)	$\gamma$	$\rho$ (Kg/m <sup>3</sup> )	$\zeta$ (%)
Concrete slab	35	0.2	2500	1
CA mortar	0.1	0.3	1700	10
Concrete roadbed	35	0.2	2500	1
UIC 60 rail	200	0.3	7850	0.1
Fastening cushion	0.006	0.3	800	10

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## 2. Loadings

Here, various loads applied on the track structure are standard earth gravity and high speed train loads. A value of  $9.81\text{m/s}^2$  is given as standard earth gravity and for transient analysis high speed train pulses are applied [1]. Fig 5 shows the load pulse of a high-speed train (type ETR-Y), which is composed of two locomotives and ten coaches and has a total length of 224.2 m. The train runs with a speed of 300 km/h.

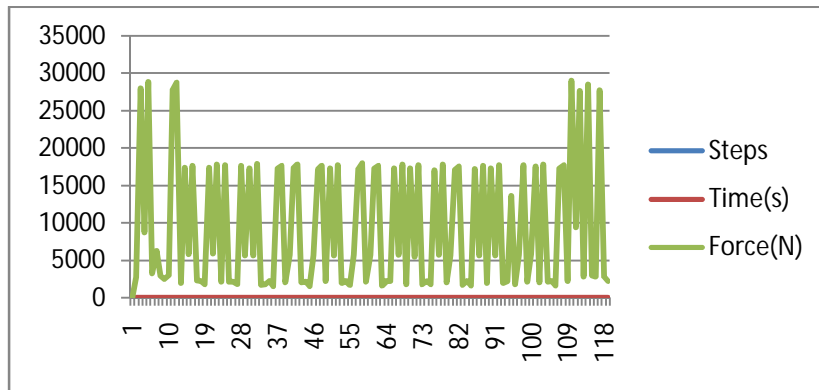


Fig 5: Applied train pulse

## 3. Results and Discussions

In this work, results considered are fatigue life and fatigue damage.. Fatigue life plot shows the available life of the structure for the given fatigue analysis and fatigue damage is a contour plot of the damage due to fatigue, at a given design life.

- Fatigue Evaluation

Fig 6(a) and fig 6(b) shows the fatigue life and damage of steel reinforced track slabs with flat footed rail. Here steel reinforced track slab with flat footed rails can withstand a minimum of 337880 load cycles and a maximum of 9980000 load cycles.

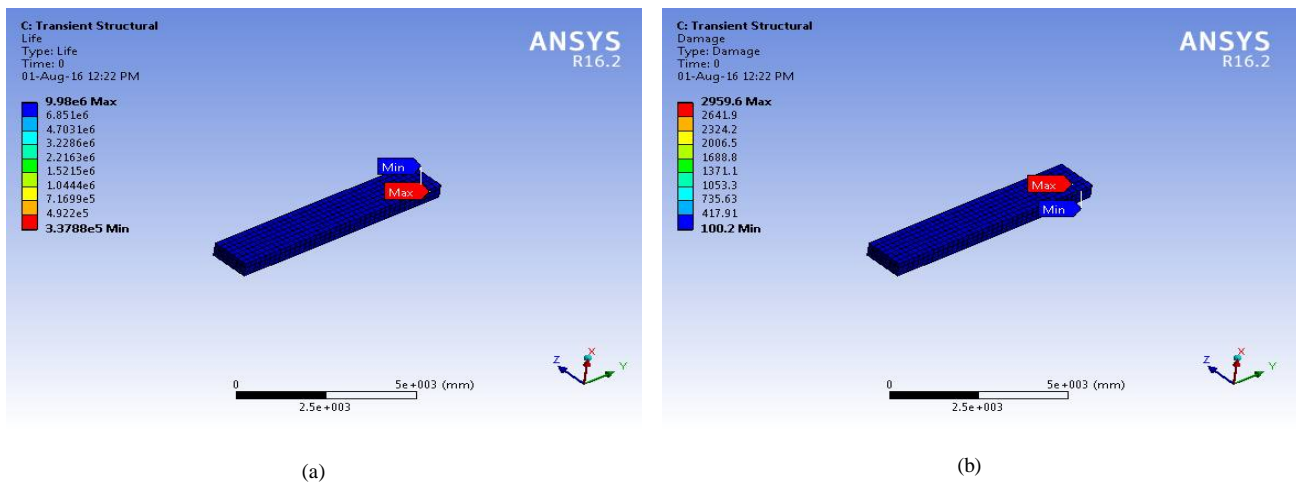


Fig 6: (a) Fatigue life, (b) Fatigue damage of steel reinforced track slab with flat footed rail

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Fig 7(a) and fig 7(b) shows fatigue life and damage of steel reinforced track slabs with bull headed rail. From figure, it is clear that this structure can withstand a maximum of 9980000 load cycles.

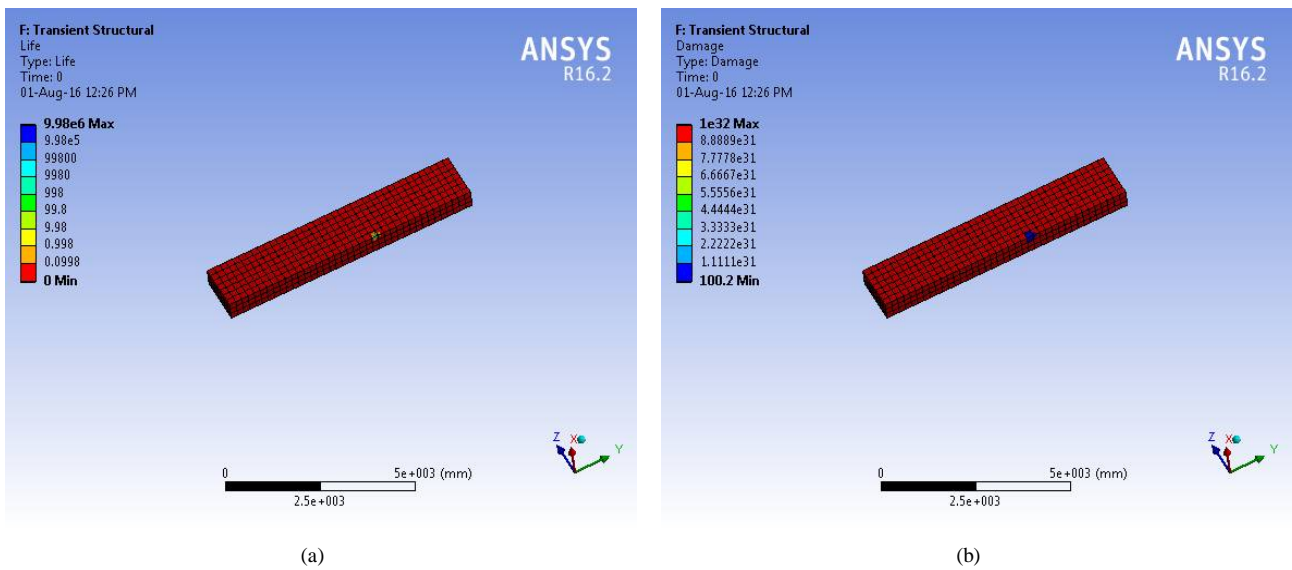


Fig 7: (a) Fatigue life and (b) Fatigue damage of steel reinforced track slab with bull headed rail

Fig 8(a) and fig 8(b) shows fatigue results of CFRP reinforced track slabs with flat footed rail. This structure can withstand a minimum of 1339900 load cycles and its minimum damage value is 100.2.

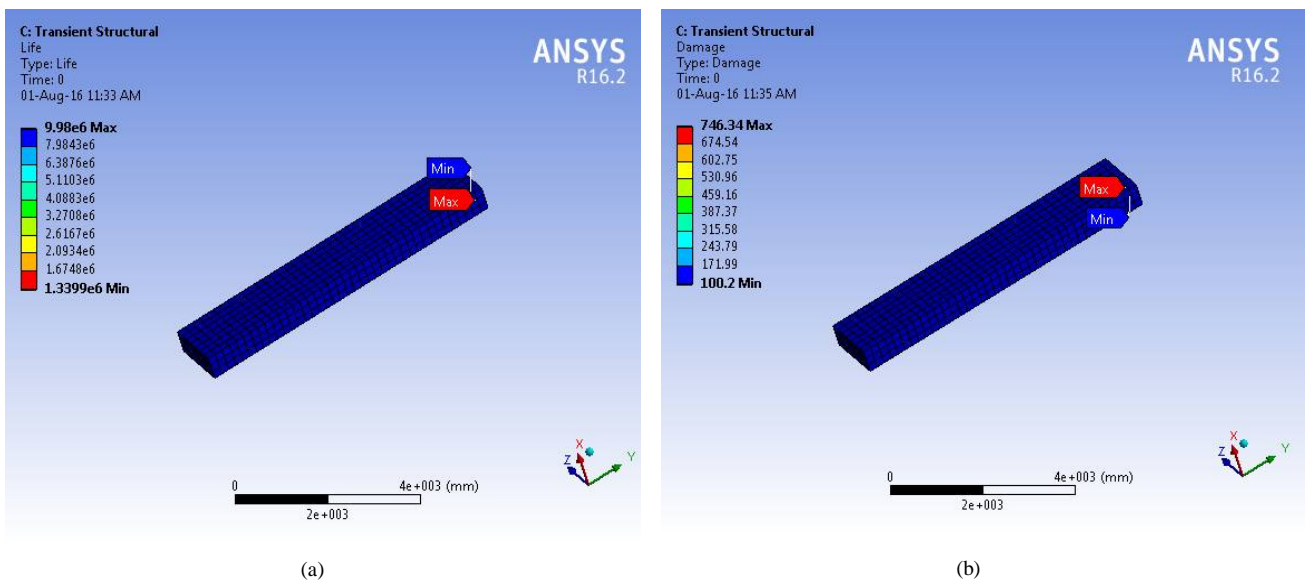


Fig 8: (a) Fatigue life and (b) Fatigue damage of CFRP reinforced track slab with flat footed rail

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Fig 9(a) and fig 9(b) shows fatigue results of CFRP reinforced track slabs with bull headed rail. From figure 9(a) it is clear that this track structure can withstand a maximum of 9980000 load cycles.

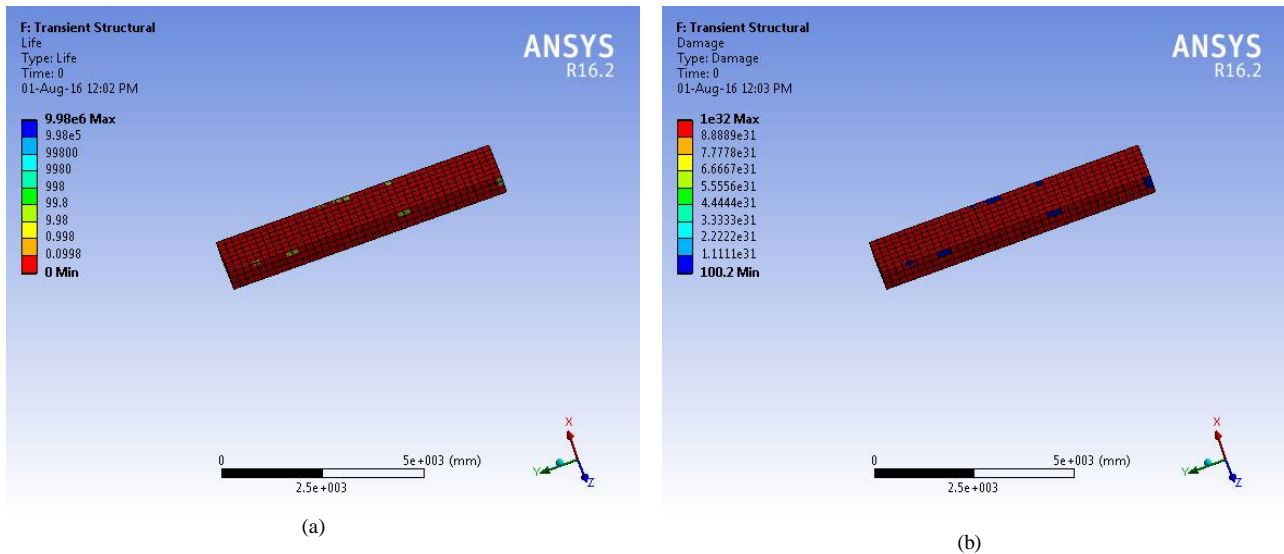


Fig 9: (a) Fatigue life and (b) Fatigue damage of CFRP reinforced track slab with bull headed rail

Table 4 shows the comparison of fatigue damage and life of track slabs with flat footed rail and bull headed rails. Track slab reinforced with CFRP bars and provided with flat footed rail shows better fatigue life and less fatigue damage.

TABLE 4: Fatigue results

	Track slab reinforced with steel bars		Track slabs reinforced with CFRP bars	
	Flat footed rail	Bull headed rail	Flat footed rail	Bull headed rail
Life (in number of cycles)	337880	0.0998	1339900	0.0998
Damage	2959.6	$10^{32}$	746.34	$10^{32}$

## IV. CONCLUSION

In this study, static structural analysis, modal analysis and transient analysis are done. For transient analysis, real high speed train pulses are applied to the track structure. Fatigue analysis is done as the post processing of transient analysis. Fatigue life and fatigue damage are the general fatigue results considered in this work. Also, the effect of two different rail profiles on fatigue behaviour of track slabs is studied. From fatigue results, following conclusions are obtained.

- CFRP reinforced track slabs with flat footed rail shows better fatigue strength than steel reinforced slab with flat footed rail, steel reinforced slab with bull headed rail and cfrp reinforced slab with bull headed rail.
- CFRP reinforced track slab can with stand 1339900 load cycles whereas steel reinforced track slabs can withstand only 337880 cycles.
- Track structures with flat footed rails suffer less fatigue damage compared to track with bull headed rails.

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Hence CFRP reinforced track slabs with flat footed rail shows better fatigue performance than steel reinforced track slabs.

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