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Experimental Investigation on the Performance of Rail Fastening Systems

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Abstract **-** One of the essential concerns in railway systems is the lifetime of rail tracks. The safety of rail fastening systems plays a significant role in rail track longevity. A standardized laboratory test procedure is required to be followed to evaluate the performance of rail fastening systems on the European railways according to EN 13146 standard series. In this study, longitudinal rail restraints and pull-out resistances were experimentally determined following EN 13146-1 and EN 13146-10, respectively. Two different types of prestressed concrete sleepers (namely B320 type and B70 type) having the same concrete quality, design axle load, and design speed but different dimensions and fastening systems were used in the experimental studies. All specimens used in this study were seen to satisfy the conditions given in the standards. It was also observed that the fastening system used in B320 type prestressed concrete sleepers results in slightly higher axial load and pull-out load capacities.

Keywords**:** Prestressed concrete sleepers; Rail fastening; Longitudinal rail restraint; Pull-out resistance; Experimental studies

1. Introduction

Sleepers, one of the most important elements of railway superstructure, transfer wheel loads to the ballast. Wheel loads create various loading effects on rails in vertical, lateral, and longitudinal directions. Longitudinal displacements and axial forces in the parallel direction to rail track are expected due to the breaking and accelerating forces [1].

One of the most sensitive elements of a railway network under these longitudinal displacements and axial forces are the rail fastening systems which mechanically hold the rail. Since their safety is essential, their performance must satisfy some standardized conditions [2].

In most of the European countries, tests for rail fastening systems are required to follow the instructions and meet the performance requirements given in the standard series called EN 13146, *"Railway applications – Track – Test methods for fastening systems"*. In this study, performance requirements of two different rail fastening systems ("System 300" and "W14") of the prestressed concrete sleepers with a design axle load of 250 kN and a design speed of 300 km/h have been checked for their longitudinal rail restraint and pull-out resistance based on the mentioned standard.

2. Test Procedure

The standard series consists of a total of 10 parts, two of which (namely determination of longitudinal rail restraint and proof load test for pull-out resistance) have been implemented in this study.

2.1. Test Procedure for Determination of Longitudinal Rail Restraint

Longitudinal rail restraint of the fastening system is determined in compliance with EN 13146-1, *"Railway applications – Track – Test methods for fastening systems – Part 1: Determination of longitudinal rail restraint."* [3]. The maximum amount of longitudinal force values that can be safely applied to the rail tracks without experiencing any plastic displacements can be obtained with this test.

The test arrangement according to the aforementioned standard is given in Fig. 1 for the determination of longitudinal rail restraint. After the sleeper that is used as the rail support is placed on a rigid base, its movement in the loading direction is restricted. The complete fastening assembly system is used for this test.

Tensile loading with a rate of 10±5 kN/min is applied to the rail until it starts slipping upon the fastening system. After this point, the load on the rail is immediately dropped to zero. This loading procedure is repeated four times. Using the obtained force-displacement curves, the longitudinal rail restraint is determined.

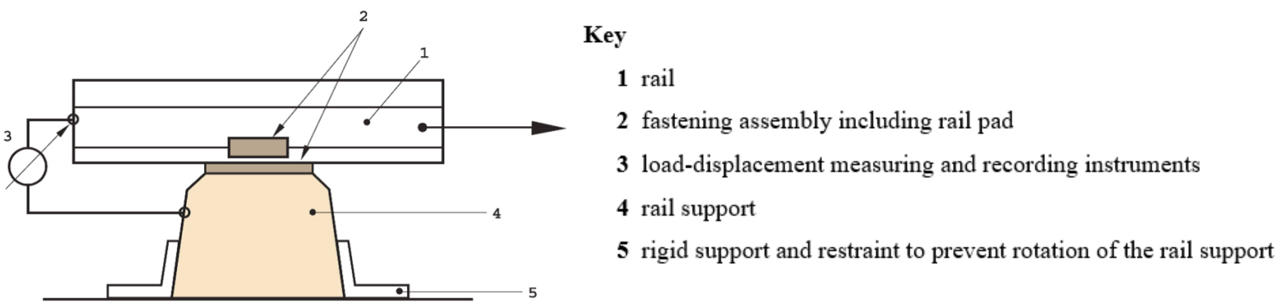


Fig. 1: Test arrangement according to EN 13146-1 [3].

2.2. Test Procedure for Determination of Pull-Out Resistance

Pull-out resistance of the fastening system is determined according to EN 13146-10, *"Railway applications – Track – Test methods for fastening systems – Part 10: Proof load test for pull-out resistance."* [4]. Performing this test, the resistance of the sleeper and screw against pull-out loading can be examined.

The test arrangement necessitated by the standard is given in Fig. 2 for the determination of pull-out resistance. The assemblage of all the rail fastening elements is not obligatory for this test. After the sleeper screw is anchored to the sleeper, an uplift force with a rate of 50±10 kN/min is applied to it until reaching the target load level, which is also referred to as prescribed proof load.

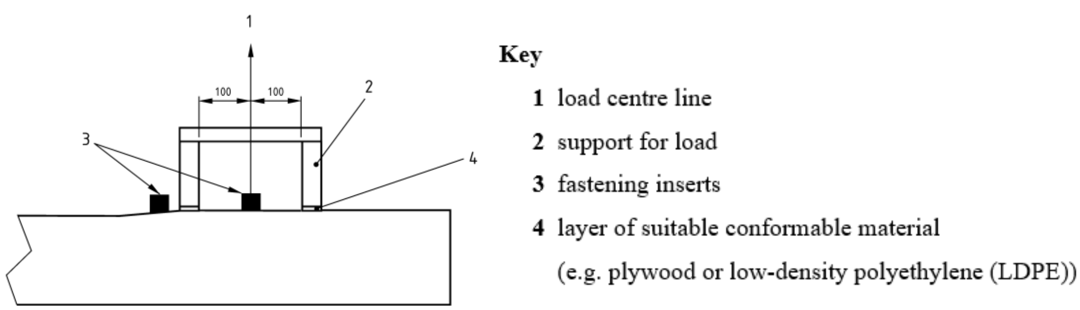


Fig. 2: Test arrangement according to EN 13146-10 [4].

3. Experimental Study

The experiments have been carried out in the Structural and Earthquake Engineering Laboratory (STEELab) of Istanbul Technical University. A total of four prestressed concrete sleepers with two different types were tested for longitudinal rail restraint and pull-out resistance using a hydraulic actuator with a loading capacity of ±250 kN. Two sleepers, one of each type, were tested for longitudinal rail restraint, while the other two were tested for pull-out resistance. Fastening systems for B320 and B70 type sleepers are "System 300" and "W14", respectively. Rail fastening systems used in the experimental studies are shown in Fig. 3. While the W14 system consists of sleeper screws, tension clamps, angled guide plate, rail pad, and plastic dowel, System 300 includes two additional components which are base plate and elastic pad.

a) System 300 *b) W14*

Fig. 3: Elements of the rail fastening systems.

3.1. Longitudinal Rail Restraint Tests

Longitudinal rail restraint tests were carried out on two sleepers. The complete fastening assembly was used for these tests. Fastening components were assembled and a rail with a length of 0.5 m was fixed to the sleeper. Sleeper screws were tightened with a torque of 250 Nm. The sleeper was turned 90 degrees and fixed with steel profiles to the loading frame. CDP25 type transducer was placed on the sleeper to measure the relative displacement of the rail. The longitudinal rail restraint test setup is shown in Fig. 4.

Fig. 4: Longitudinal rail restraint test setup.

Using a special equipment, the tensile load was applied to rail with the hydraulic actuator at a rate of 10 kN/min. Applied force and relative displacement of the rail were measured and observed. The load was suddenly decreased to zero when the rail slipped. This procedure was repeated three times more.

Force-displacement graphs obtained by the longitudinal rail restraint tests are shown in Fig. 5 and 6. D_1, D_2, and D_3 values for each cycle are shown on the graphs. D_1 is defined as the maximum longitudinal displacement experienced by the rail during the loading and D_2 is the residual longitudinal displacement measured in the rail after the load is removed. D_3 is the elastic longitudinal displacement of the rail before it starts slipping and it is calculated as the difference between D_1 and D_2.

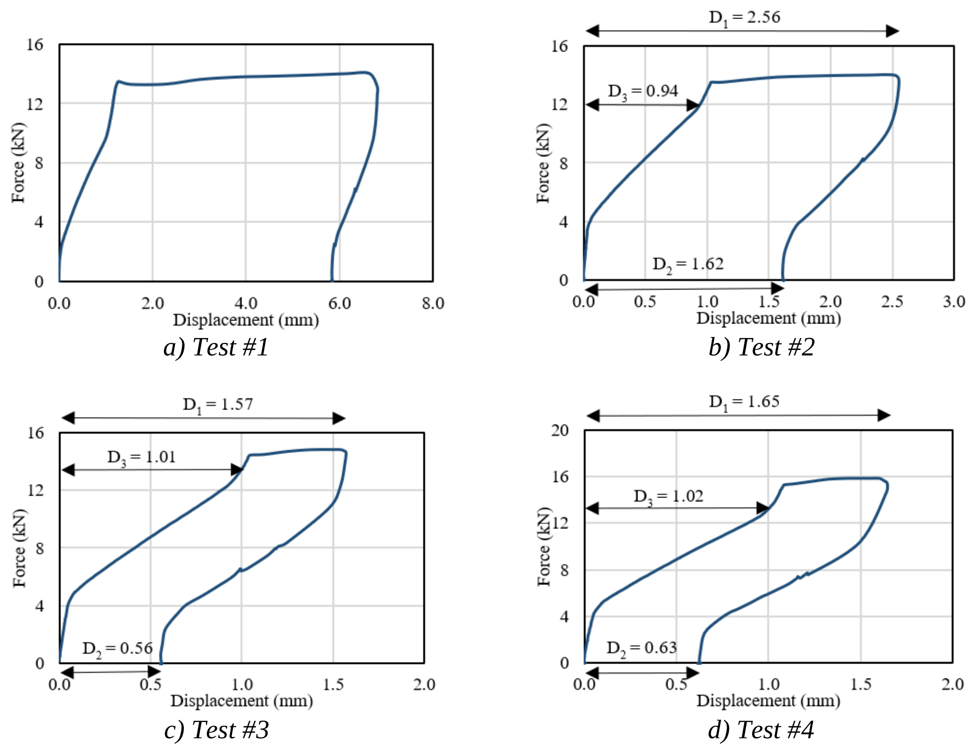


Fig. 5: Longitudinal rail restraint test results for B320 type sleeper.

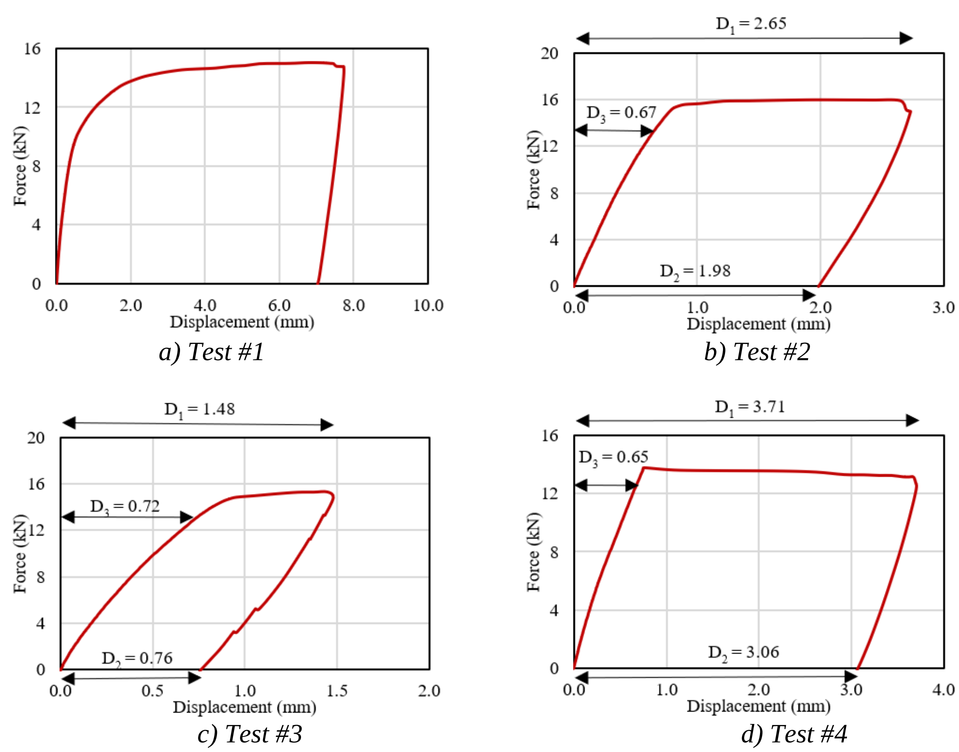


Fig. 6: Longitudinal rail restraint test results for B70 type sleeper.

The maximum rail axial load in the elastic rail displacement region (F) is the force value when the longitudinal rail displacement is equal to D_3. The F value should be neglected for the first cycle as stated in the standard. Longitudinal rail restraint equals the mean of the remaining three F values, which are listed in Table 1 for the tested sleepers. Both of the sleepers met the performance requirement as the longitudinal restraint exceeded the prescribed load value of 9 kN.

Table 1: Calculated F values as a result of longitudinal rail restraint tests.

Test	F (kN)	
	B320	**B70**
#2	11.98	13.60
#3	13.58	12.86
#4	13.59	12.26
Mean	**13.05**	**12.91**

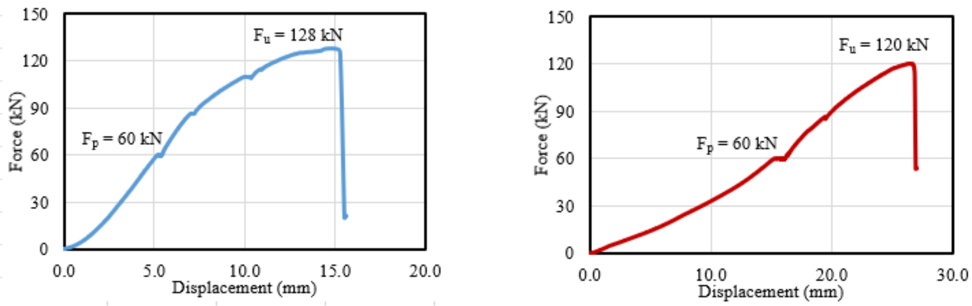
3.1. Pull-Out Resistance Tests

Pull-out resistance tests were performed on two sleepers. Only one component of fastening system, sleeper screw, was used in pull-out tests. Test setup is shown in Fig. 7. The sleeper was fixed with steel profiles to the loading frame. The distance between the supports was 200 mm.

Fig. 7: Pull-out resistance test setup.

The screw was pulled with a hydraulic actuator at a rate of 50 kN/min. The prescribed proof load (F_p) for both sleepers was 60 kN. The load was maintained for three minutes at this load level, and the sleeper was inspected for damage. Since there was no damage on either of the sleepers at proof load level, it can be said that both specimens met the requirements.

Then, the load was increased until failure. Ultimate failure loads (F_u) for B320 and B70 sleepers were obtained as 128 and 120 kN, respectively. Failure type was the pulling-out of screws for both sleepers. Force-displacement curves for pull-out tests are shown in Fig. 8. State of the sleepers, in prescribed proof and failure load levels, are shown in Fig. 9 and 10.

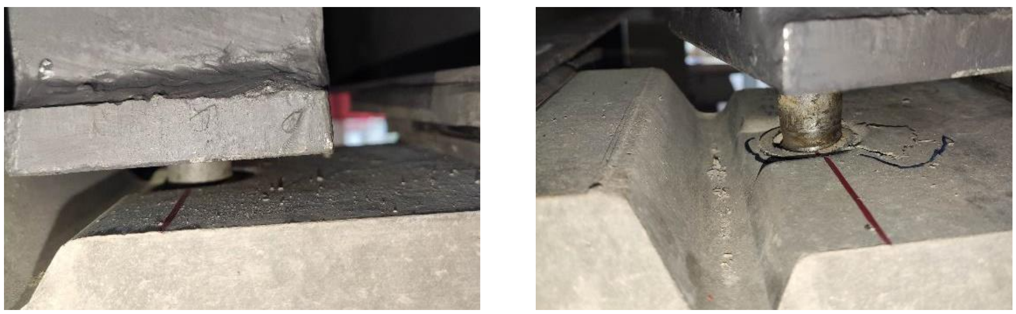


a) B320 type sleeper *b) B70 type sleeper*

Fig. 8: Pull-out resistance test results.

a) Prescribed proof load *b) Ultimate failure load*

Fig. 9: Pull-out test states of B320 type sleeper.



a) Prescribed proof load *b) Ultimate failure load*

Fig. 10: Pull-out test states of B70 type sleeper.

4. Conclusions

Longitudinal rail restraint and pull-out resistance tests were performed to investigate the performance of rail fastening systems in compliance with "*EN 13146: Railway applications – Track – Test methods for fastening systems*". Two different prestressed concrete sleeper types called B320 and B70 with different fastening systems, namely "System 300" and "W14", were used in the experiments. The following conclusions can be derived:

- Longitudinal rail restraints for B320 and B70 type sleepers are 13.05 and 12.95 kN, respectively. Since these values are larger than the prescribed performance requirement (9 kN), both fastening systems satisfied the demands of the EN 13146-1 standard.
- No sign of damage was observed either on the sleeper or the fastening system when reached the prescribed proof load (60 kN) in the pull-out tests. Both of the fastening systems performed satisfactorily according to the EN 13146-10 standard. Failure loads for pull-out tests of B320 and B70 type sleepers were measured as 128 and 120 kN, respectively.
- Average value for elastic longitudinal displacement of the rail before it starts slipping (D_3) was calculated about 1.0 mm for B320 type sleeper and 0.7 mm for B70 type sleeper in each cycle of the tests. Thus, it can be stated that satisfactory results with low dispersion were obtained in the tests.
- Apart from the tests of which results were presented above, two longitudinal rail restraint tests and two pull-out resistance tests were additionally conducted for the fastening system used in B320 type sleepers. Their mean D_3 values were determined as 0.85 mm and 0.80 mm. Also in pull-out resistance tests, no damage was detected on the fastening system and ultimate failure loads were recorded as 124 kN and 133 kN. Very good compatibility were obtained in the performed tests.
- Both longitudinal rail restraint and the pull-out failure load were observed to be slightly larger for the fastening system "System 300" used in B320 type sleepers when compared with the fastening system "W14" used in B70 type sleepers.

Acknowledgements
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