GEOTECHNICAL EVALUATION AND NUMERICAL MODELING OF RAILWAY TRACKS ON COMPACTED SUBGRADE

by

AMIT SHARMA

Department of Civil Engineering

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA

FEBRUARY 2007

Railway tracks - Geotechnical evaluation

CERTIFICATE

This is to certify that the thesis entitled "**GEOTECHNICAL EVALUATION AND NUMERICAL MODELING OF RAILWAY TRACKS ON COMPACTED SUBGRADE**" being submitted by **Mr. Amit Sharma** to the Indian Institute of Technology Delhi is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and results presented in this thesis have not been submitted, in part or full, to any University or Institute for the award of any degree or diploma.

J. T. Shahu.

(DR. J.T. SHAHU)
Assistant Professor

(DR. K.G. SHARMA)
Professor

Department of Civil Engineering
Indian Institute of Technology Delhi
New Delhi – 110016
INDIA

ACKNOWLEDGEMENT

On the completion of this work, it is my great proud and privilege to express my deepest gratitude with great appreciation to my supervisors, Dr. J.T. Shahu and Dr. K.G. Sharma for their irreplaceable encouragement, inspiring guidance, keen interest, unfailing support and constant encouragement throughout this study. Persons of myriad skills, they eased the way of my work by their wonderful contribution. Their volunteered hours of valuable time helped me to put my best foot forward in right direction. Their vast knowledge and experience on the subject made this study possible and even more enjoyable.

I am indebted to my M.Tech. supervisor, Dr. A. Varadarajan (former Dogra Chair Professor, IIT Delhi) for his useful suggestions, knowledge and guidance provided to me during my M.Tech., which acted as a source of inspiration for me to go for doctoral study.

My sincere thanks to Dr. K.K. Gupta, Geotechnical Laboratory Incharge, IIT Delhi, for providing me with necessary testing facilities and other related infrastructures required for conducting my research work in time.

I would also like to thank my friends Dr. Sanjaya Kumar, Mr. Rakesh Kumar Sharma and Mr. Altaf Usmani for having useful discussions.

My thanks goes to Soil and Rock mechanics laboratory staff; Mr. Manoj Kumar, Mr. D.S. Gussain, Mr. D. Biswas, Mr. Neeraj Gupta, Mr. Jodh Raj Meena and Mr. Munni Lal for their cooperation in carrying out the experimental work.

Thanks to Mr. K.K. Bali and Mr. Ram Kumar, workshop staff IIT Delhi, in helping the fabrication of model steel tank.

I would also like to thank Civil Engg. Department IIT Delhi, for allowing me to use MTS machine in the Structures Strong Laboratory for conducting Model track testing.

The author acknowledges the RDSO Lucknow, (India) for their help rendered in procuring the railway track ballast material needed for testing from their stockyard at New Delhi. The valuable and live discussion with the RDSO technical committee members regarding various practical aspects of railway track is also acknowledged; some of the points discussed have even been graciously incorporated in the study.

The author is grateful to Dr. A.K. Dhawan, Director, Central Soil & Materials Research Station (CSMRS), Ministry of Water Resources, Olof Palme Marg, Hauz Khas, New Delhi-110016; for allowing him to use large scale triaxial shear testing facilities for testing of ballast material. Sincere thanks to the team of scientists especially Mr. N.P. Honkanadavar and the staff members of rockfill technology unit, for their help during the experimental work related to ballast testing.

I wish to thank Mr. Amit Kumar Goswami and Mr. Jogeshwar Pal Singh, project assistants, for assisting me in my experimental testing work.

Last but certainly not least, words alone cannot express my deepest gratitude for the constant support, understanding and love that I received from my family during the tenure of this study that provided me the necessary impetus to work on this thesis.

ASharma.

(Amit Sharma)

ABSTRACT

Given the fact that roadways are already saturated and congested, the only viable alternative for the growth of land transportation remains the railways that can either be achieved by the upgradation of existing tracks or by the construction of new ones as per the requirement. In the past, the track superstructure has received major attention; however, the present study is more oriented towards the substructure design, i.e., the design is related to the material and thickness of various base layers of a track. The substructure attains significance because the performance of the superstructure is directly dependent on the support provided from beneath. Moving trains transmit load to the soil below it through ballast and sub-ballast layers.

The present study has been carried out in four main parts, namely, geotechnical characterization of materials and interfaces of various track layers; half-scale, full panel laboratory model tests; elasto-plastic three-dimensional finite element analysis of track structure; and formulation of design methodology. Geotechnical characterization of different track layer materials and interfaces have been carried out. Tests have been conducted on ballast and sub-ballast materials conforming to Research Design and Specifications Organization (RDSO), Indian Railways. Tests on subgrade soils have been conducted on Indo-Gangetic alluvial silts characterized by variation in their plasticity.

Both monotonic and slow cyclic triaxial tests have been conducted on three different Indo-Gangetic alluvial silts, namely, Delhi silt, Allahabad silt and Kanpur silt as subgrade material. The subgrade soil behaviour has been analyzed in quasi-saturated, critical state soil mechanics framework. Based on cyclic tests, simple correlations have

been given for development of cumulative plastic strain and threshold stress of the subgrade soils under cyclic loading. Parameters of bilinear log-log relationship for development of cumulative plastic strain have been evaluated for Indo-Gangetic alluvial silts. A relationship between threshold stress and plasticity index is proposed for low plasticity compacted silts pertaining to low effective confining stresses.

Drained monotonic and cyclic triaxial tests have been carried out on two different gradations (fine and coarse gradation) of sub-ballast material. These materials are locally available Badarpur sand (fine material) and crushed Delhi Quartzite (coarse material) respectively. The tests have been carried out on 38 mm diameter specimens for fine material and 100 mm diameter specimens for coarse material. Large-size drained montonic triaxial tests on 380 mm diameter specimens have been carried out on ballast materials – two conforming to RDSO specifications and two other for comparison. Both ballast and sub-ballast materials were modeled in terms of strength parameters of Mohr-Coulomb model. Important conclusions have been derived from particle breakage analysis of ballast samples.

To study the interface properties of various interfaces found within the track layers, direct shear testing has been carried out to characterize different interfaces by means of shear stiffness, normal stiffness and coefficient of interface friction. Tests have been conducted by simulating various interfaces that exist in typical north Indian wooden or steel sleeper track in laboratory direct shear apparatus. The interfaces tested are between subgrade and sub-ballast; sub-ballast and ballast; ballast and sleeper; and sleeper and rail. Series of normal load tests and direct shear tests are conducted in the laboratory on various interfaces. Both small size and large size direct shear tests have been carried out depending on the particle size of the material constituting each layer on either side of an interface.

A half-scale, adequately instrumented, laboratory model testing of railway track has been carried out. Series of tests have been performed on model railway tracks comprising of different thicknesses of granular layers, namely, ballast and sub-ballast, and supported on different types of subgrades. A sinusoidal loading corresponding to 300 kN axle load in the prototype was applied on steel rail supported by model sleepers and a steel rail. Based on the geometric and loading symmetry, only one-half of the track has been modeled. The main objectives of the model tests are to evaluate the influence of granular layer thicknesses and subgrade type on load-deformation behavior of railway track under static and cyclic loading and to use the results of model track for calibration of numerical model developed in this study. The testing has been carried out for tracks laid on both compacted and remoulded soil subgrades. Model track was constructed using the same geomaterials on which laboratory tests were conducted.

Finite element analysis of a railway track with track superstructure (rail and sleepers) along with track substructure layers, viz., subgrade, sub-ballast and subgrade is presented. For this purpose, a three-dimensional (3D) finite element analysis has been conducted using the commercially available software package ABAQUS. The predicted results from the analysis are compared with the model tank test results. Next an elasto-plastic finite element analysis of the prototype railway track has been conducted using the material constitutive parameters evaluated from the laboratory tests. Mohr-Coulomb yield criterion has been used to simulate the behaviour of granular materials and Modified Cam-Clay model has been used to simulate the behaviour of subgrade soil. The numerical

analysis also includes a parametric study of the response of a track with varying modulus of elasticity of ballast, sub-ballast and subgrade; thickness of ballast and sub-ballast layer; moment of inertia of rail; and sleeper spacing assuming linear, elastic response.

Finally, a rational design methodology for the determination of a railroad track has been formulated combining the two aspects of the study conducted, viz., experimentation and finite element analysis. The design methodology is based on limiting the maximum deviator stress induced on the subgrade surface due to traffic loading below the threshold stress of the subgrade soil, by providing an adequate formation thickness. The design procedure so established has a direct practical application in real life for the construction of railway track to be laid on compacted subgrade passing through Indo-Gangetic Plains.

To summarize, the study presents design methodology backed by suitable geotechnical laboratory testing of the track layer constituent materials and numerical stress-deformation analysis (3D finite element analysis) to arrive at safe design of the railway track under different loading conditions in terms of thickness of its various constituent granular layers.

CONTENTS