ANALYSIS AND DESIGN OF
ON-GRADE REINFORCED CONCRETE
TRACK SUPPORT STRUCTURES

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SUMMARY

For the improvement of rail service, The Department of Transportation, Federal Rail Administration, is sponsoring a test track on the Atchison, Topeka, and Santa Fe Railway. The test track will contain nine separate rail support structures, including one conventional section for control and three reinforced concrete structures on grade, one slab and two beam sections. The analysis and design of these latter structures (ref.1) was accomplished by means of the finite element method, NASTRAN, and is presented herein.

INTRODUCTION

In order to provide fast, economical rail service, the development of improved, low maintenance track support systems is required. While seemingly a simple problem, the system of rail-fastener-structure-subgrade poses complex interaction problems. In addition, a random distribution of asymmetric lateral loads is applied by moving rail traffic.

In an effort to provide test data for use in developing such support systems, three non-conventional track structure systems are to be included as parts of the approximate two mile length of test track to be constructed by the U.S. Department of Transportation and the Santa Fe Railway Company. The three non-conventional track support structures, each 244 meters in length, are: twin cast-in-place continuously reinforced concrete beams joined by gaging (cross) members; a continuously reinforced concrete slab; and a system of twin precast beams made continuous at abutting ends and joined by gaging members.

As part of the research program related to developing practical, low maintenance, high quality track structures, studies were carried out (refs. 2 and 3) to produce performance criteria and specifications for such structures. Analyses and tests showed that distinct subgrade pressure pulses are imparted by every passing axle load, and that subgrade deterioration is related to the number of impulses. As a result of those studies it was concluded that track support structures having a high structural rigidity would effectively reduce the load cycles to one per truck. A specific stiffness was determined and specified as design criteria, along with vertical and lateral wheel-rail load magnitudes. These criteria formed the basis for the static analyses performed to design and evaluate the sections shown in figure 1.

In the design and construction of the test sections the goal of removing all possible secondary variables and "weak links" was pursued in an effort to create structures whose performance and safety would be unimpaired. A test embankment was designed and constructed, under close control, to create uniform subgrade conditions throughout the entire test track. An unusual rail fastener was selected to insure that it would not be a controlling "weak link."

These instrumented systems will be integral parts of the Santa Fe's single track mainline, and will carry both eastward and westward trains approaching 50,000,000 gross tons annually, at speeds up to 120 kilometers/hour. Thus, the systems will be subjected to rigorous service, and it is anticipated that significant results for future use will be produced through the instrumentation and the observation of the performance of the components of the system.

In order to achieve the necessary safety in design, and handle the complex interaction and boundary conditions, the finite element method was chosen for analysis, and NASTRAN was used as the analytical tool. Design was accomplished using a combination of working stress and ultimate strength methods. All work was done in the British system of units.

THE FINITE ELEMENT MODEL

The finite element models formulated for analysis are shown in figure 2. The models represent the rail, rail fastener, concrete structures and subgrade.

Rail

Classically, little attention has been given to the torsional action of the rail in the track system. Hence, only bending properties were available and the membrane analogy was applied to calculate the torsional coefficient for use in the analyses. CBAR elements were used to represent the rail in the NASTRAN model.

Fastener

The direct fixation fastener selected for the project provides restraint to the rail in each of the six degrees of freedom. The selected fastener has not been in service, although a smaller scale version is on the market. Prestressed elastomers are utilized to provide restraint cushioning. The prototype fastener was tested to determine an order of magnitude for the load-deflection relations used for the CBAR element. The OFFSET provision was implemented to provide geometrical compatibility for the rail-fastener-slab connectivity.

Slab and Beams

Since the distribution of subgrade pressures was desired as a result of the analyses, and the slab and beams were orthotropic in nature, the CQUAD 2 element was used with a MAT 2 formulation (ref. 4) to yield orthotropic properties. Longitudinal stiffnesses were as specified by the design criteria, while transverse stiffnesses were the result of transverse reinforcing for temperature and construction requirements. All design was based on cracked section properties.

Subgrade

The subgrade was represented by three grounded CELAS 1 elements connected to each GRID point having CQUAD connectivity. One spring was in the vertical plane to represent a Winkler foundation. Properties used for these springs were obtained from field plate bearing tests (refs. 1 and 5) as shown in figure 3. Correlation for these properties were obtained using Vibroseismic methods (refs. 6, 7 and 8), and construction control tests obtained during construction of the test embankment (refs. 9 and 10). Two springs were used in the horizontal plane (longitudinally and transversely) to represent tractions on the concrete-subgrade interface. The elastic properties were derived from field tests (ref. 1) using large slabs with surcharge pressures; typical results are presented in figure 3.

ANALYSIS PROCEDURES

A single preprocessor was written to generate the bulk data required for the structures, varying geometry, material properties, and connectivity as required. All analyses were performed on the Control Data Corporation Cybernet System using NASTRAN and, for simple parametric studies, EASE. Rigid Format 1, with RESTART, was used for all NASTRAN activity.

EASE models of a rail-fastener system on an infinitely stiff supporting structure were analyzed to determine the influence of rail torsional properties, and the effect of variation of fastener properties, on the distribution of load to the structures.

Influence Length Study

A single axle and single truck load, figure 4, were applied to long models of both structures (2220 GRID, 520 CBAR, 5550 CELAS 1, and 1272 or 1440 CQUAD 2, having about 5.2 degrees of freedom average per GRID) to obtain influence lengths and approximation errors. Results of these studies indicated that one-half car length models would be satisfactory, but lateral load positioning required analysis of car length models until the occurrence of deflected structure symmetry was verified.

Design Analyses

Car length models were used to analyze both the infinite and finite (end of test section) cases. Single Point Constraints were used to create a coupler to coupler model with plane of symmetry conditions in the deflected structure, while Multi-Point Constraints were used to give a mid-car to mid-car model with antisymmetric conditions in the deflected structure. Models with "softened" subgrade were also analyzed for the infinite case. Results of these analyses are shown in figures 5 and 6.

The finite structures were modeled by allowing inplane vertical displacements with no rotations of the GRIDs on one boundary, while allowing complete freedom on the other boundary for all but the rail GRIDs. Rail GRIDs were allowed to displace in the vertical plane with no rotation. A comparison of the spread of the beam structures, obtained for the infinite and finite cases, is shown on figure 6.

DESIGN

ELFORCE output was used to verify the adequacy of the design criteria, to apportion reinforcing for the slab and beam structures, and to design tie-rods to restrain beam spread. The beam structures were reinforced for combined biaxial bending and torsion. Subgrade pressure distributions and structure-subgrade shears were evaluated, and validity of properties verified. Regions or items of probable "high maintenance" were located and inspection procedures formulated.

The project will be instrumented for strains in the rails, reinforcing, and embankment; for stresses in the subgrade; and for loads transmitted through the fasteners. In addition, a calibration series of static loads has been recommended to allow verification of the design procedures and analytical methods, and to allow a correlation base for dynamic readouts and subsequent analyses.

CONCLUSION

The availability of NASTRAN was invaluable in carrying out this project since the sponsor had specified that no new codes were to be created. A more realistic design was achieved than would have been accomplished using conventional methods (ref. 11), or more simplistic models, which would not have defined the three-dimensional nature of the structure and would have resulted in an inadequate design.

ACKNOWLEDGMENTS

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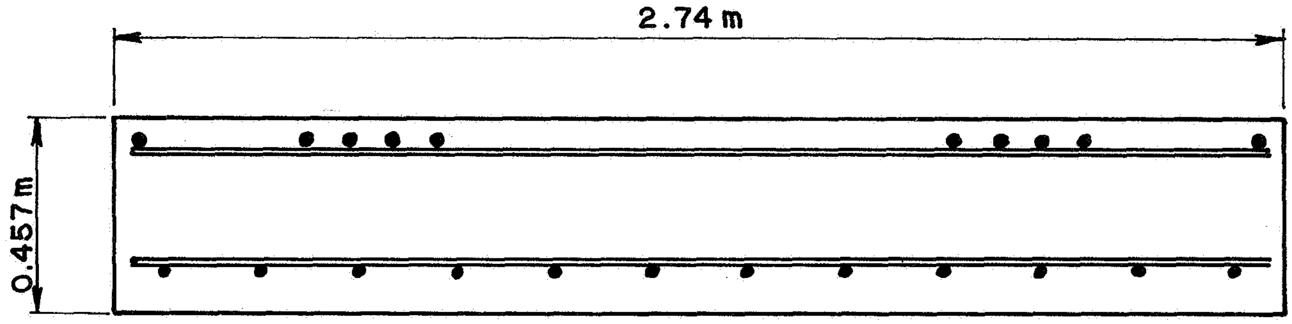
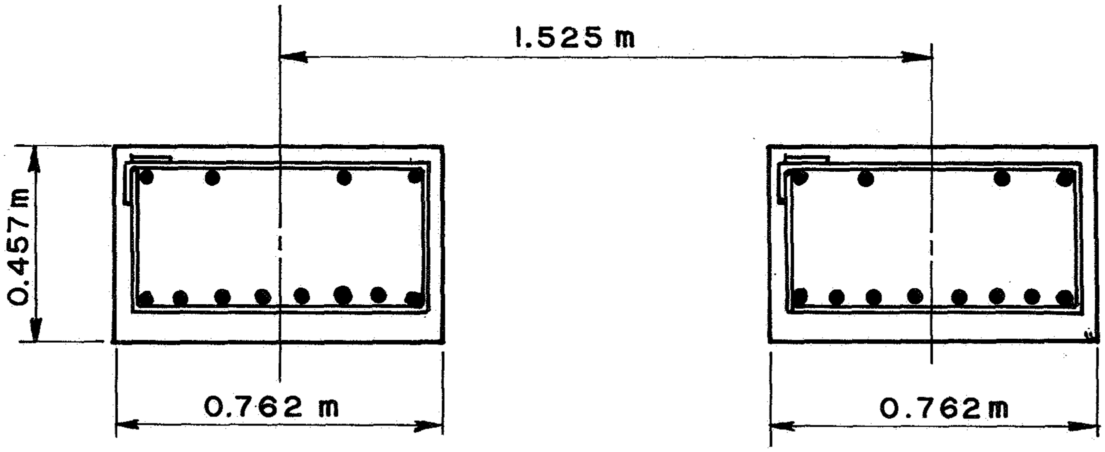
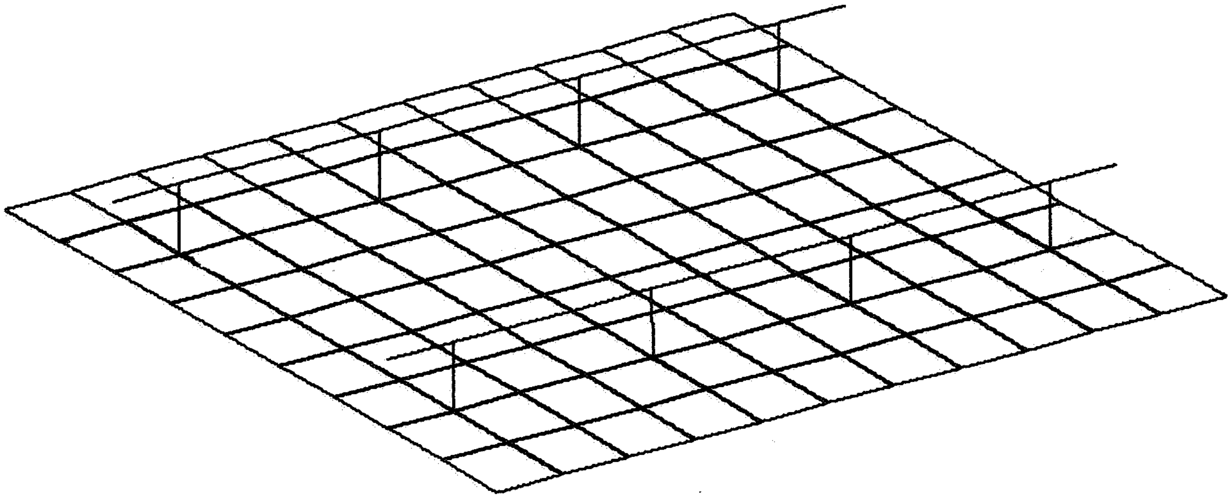


TYPICAL SLAB SECTION

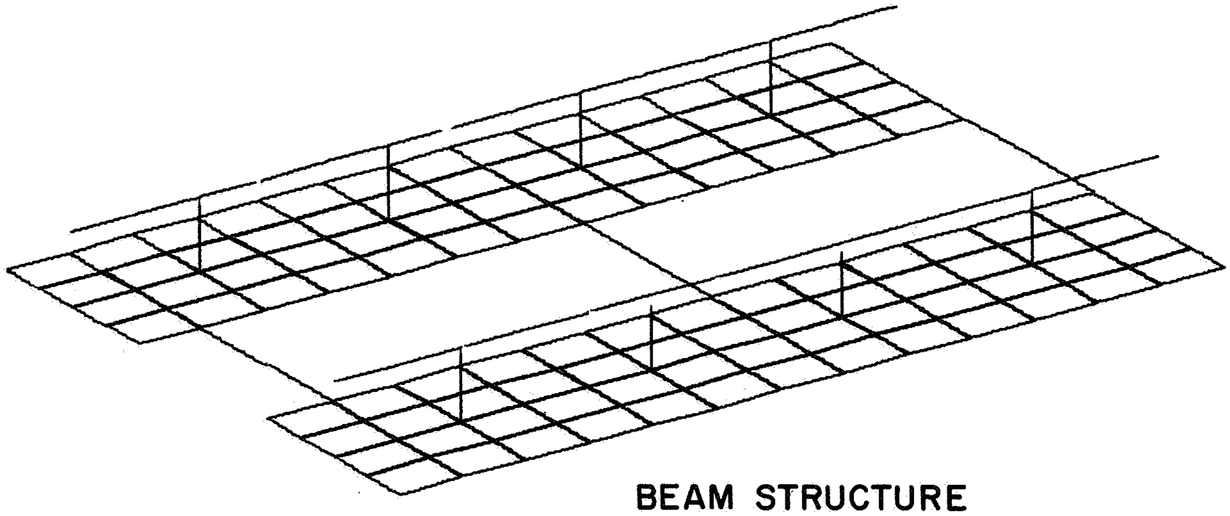


TYPICAL BEAM SECTION

FIGURE I: TYPICAL SECTIONS

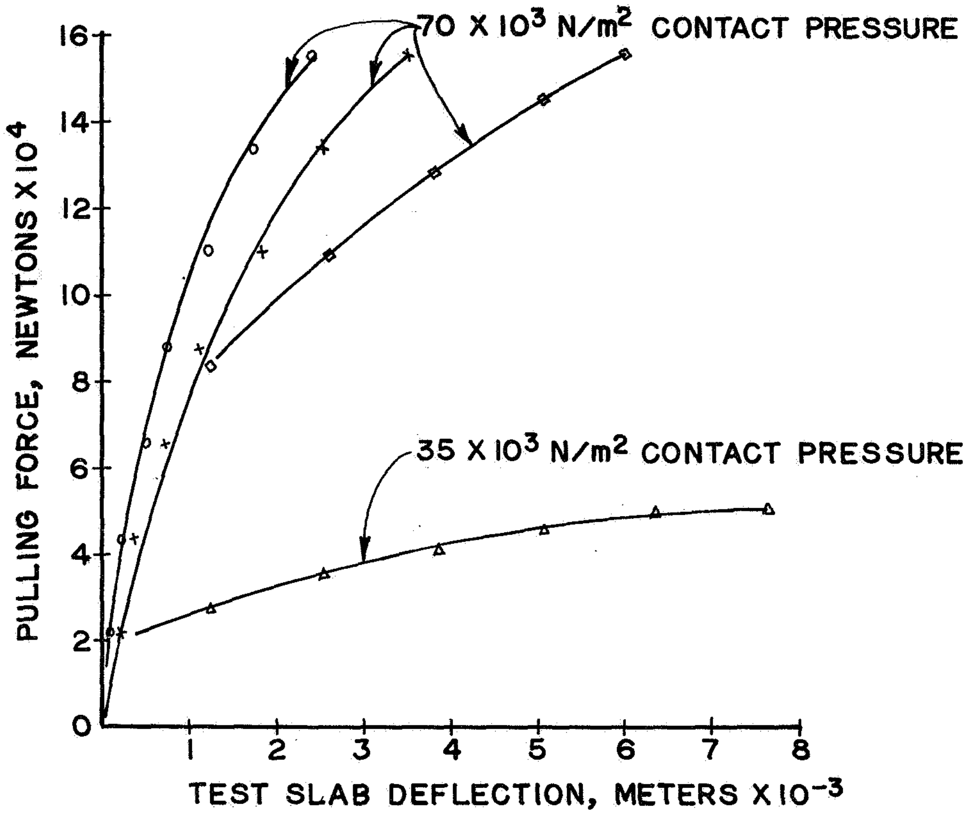


SLAB STRUCTURE



BEAM STRUCTURE

FIGURE 2: ELEMENT CONNECTIVITY



BALLAST SHEAR TEST RESULTS

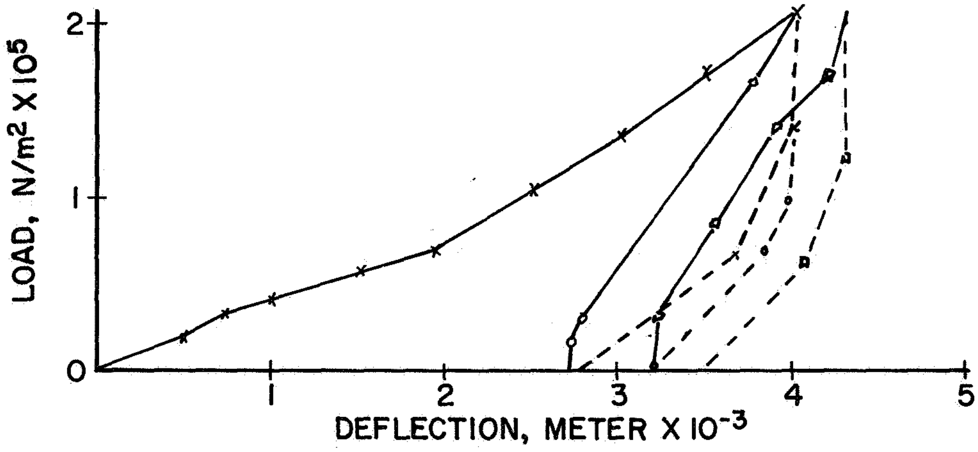
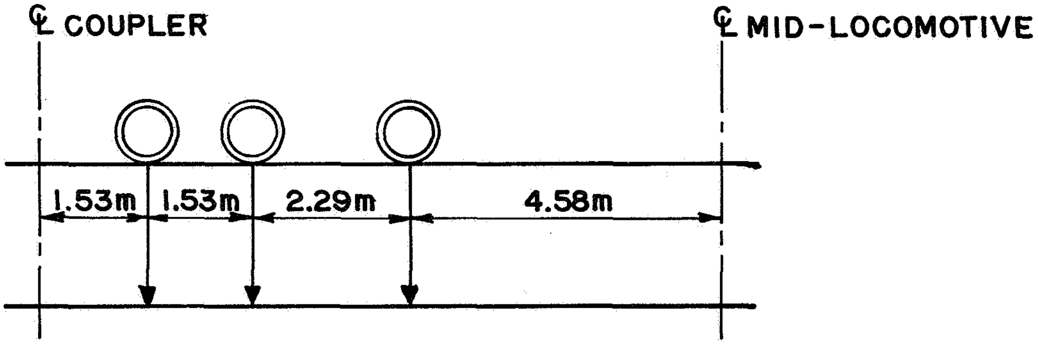
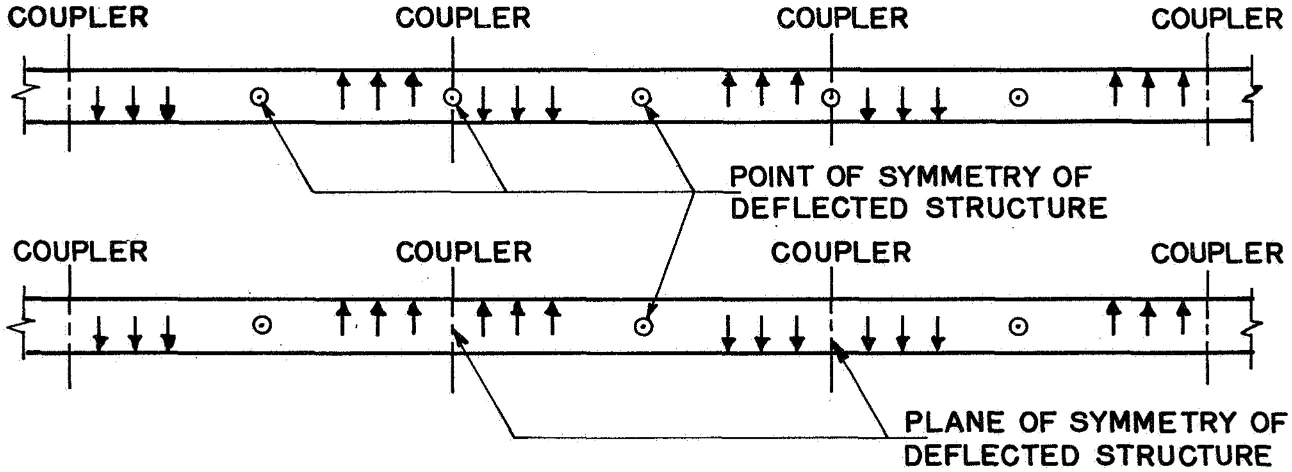


PLATE BEARING TEST RESULTS

FIGURE 3



IDEALIZED LOCOMOTIVE TRUCK



IDEALIZED LATERAL LOAD PATTERN

FIGURE 4

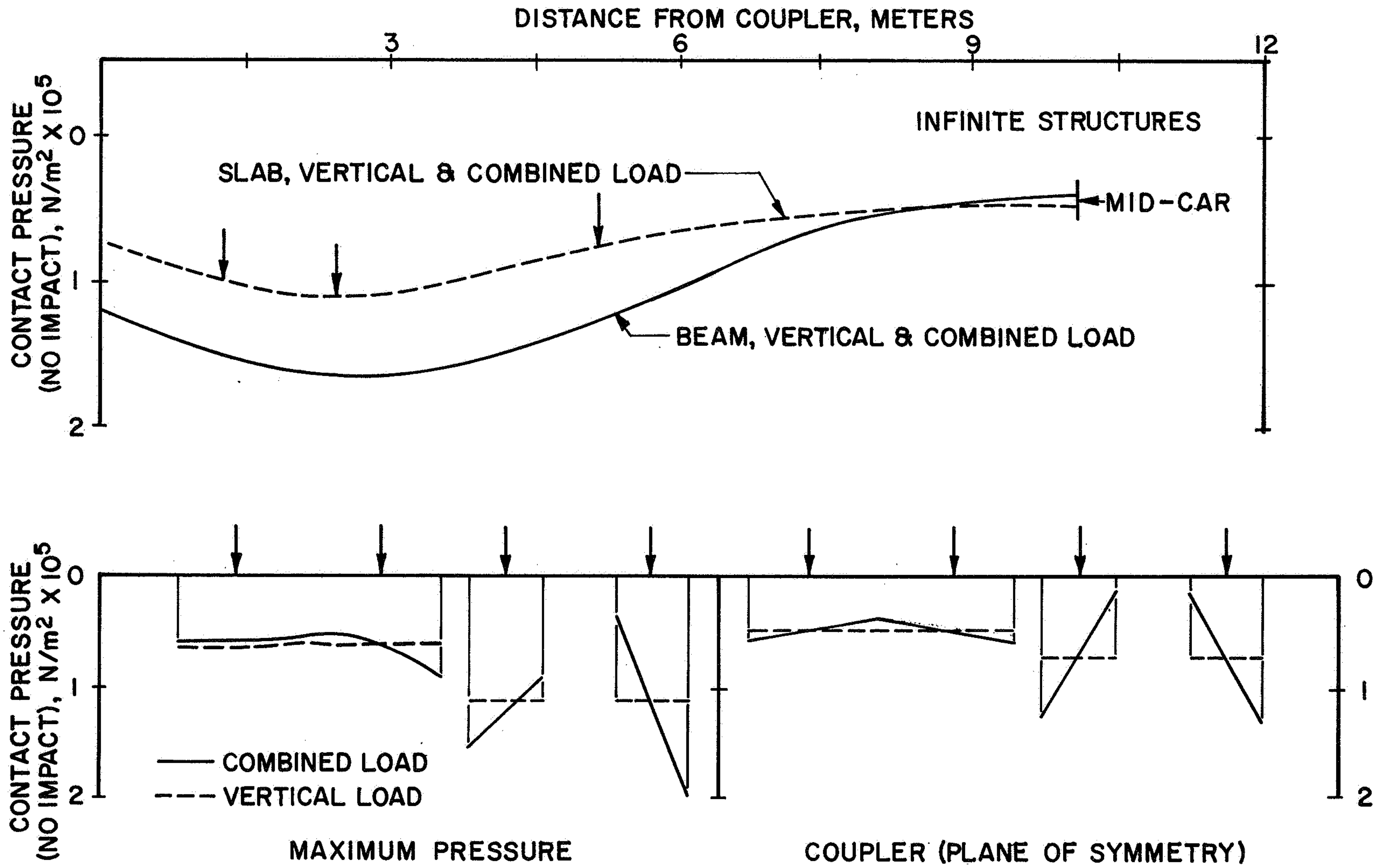


FIGURE 5: CONTACT PRESSURES

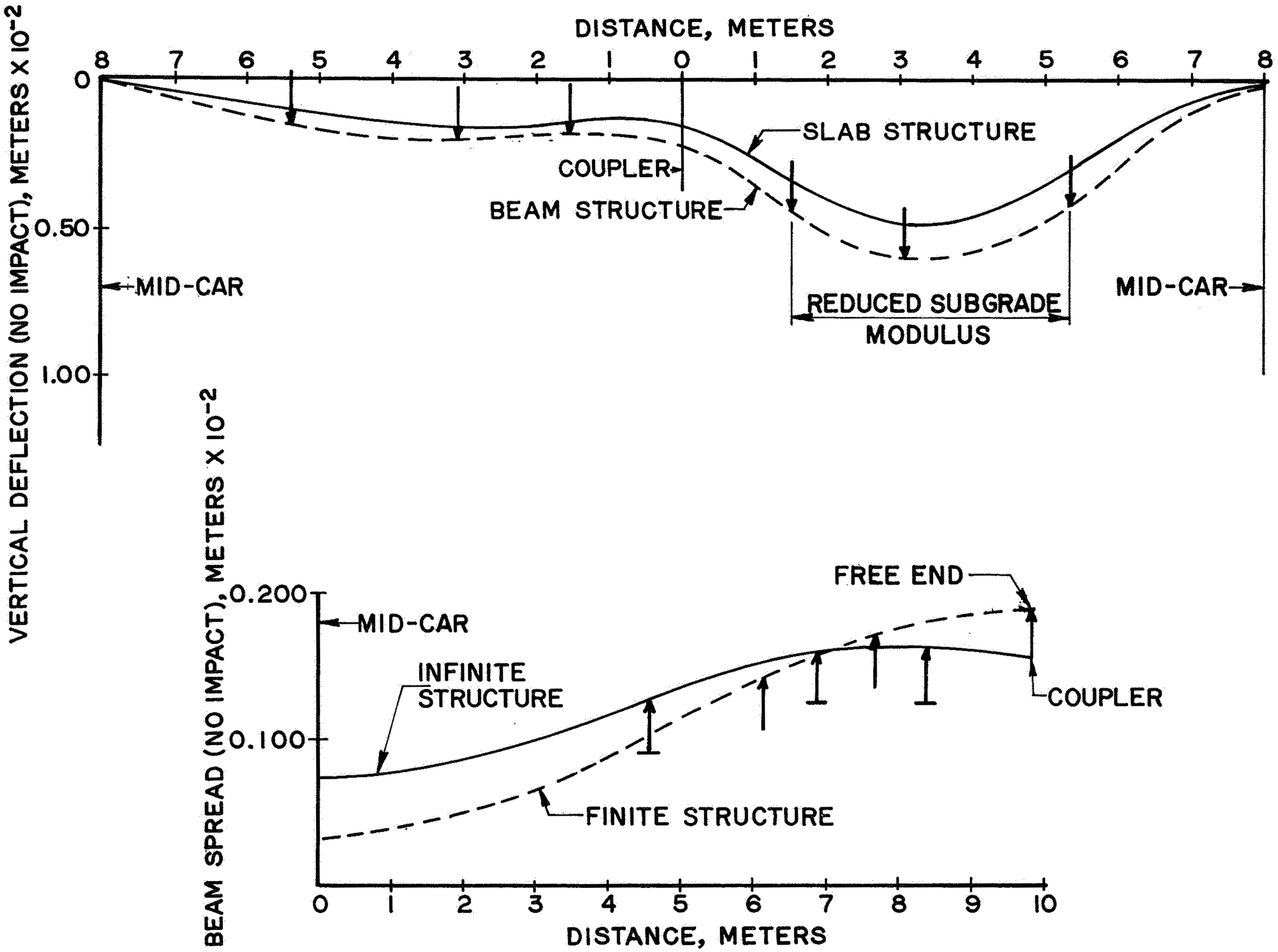


FIGURE 6: STRUCTURAL DEFLECTIONS