Numerical Studies on Detailing of Link Slab for Highway Girders Considering Cracking Behavior

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Abstract

Continuity of the deck can be treated to eliminate gaps between adjacent spans providing smooth riding with link slab. The link slab would accommodate all movements into the structure by means of axial deformation, rotation and translation as boundary condition counteract with structural behavior of adjacent spans. The aim of the herein investigations is to determine the behavior of the link slab under these boundary conditions. Numerical studies on detailing of link slab by means of the 3-dimensional nonlinear finite element method using the microplane model (MASA3) are employed for the investigation. Some numerical results are also compared with the experimental results of the true-scale concrete link slabs under mid-span loading in terms of load-deflection relationship and crack distribution. In the experimental testing, there are considering variable length of lap reinforcement which can be classified to 3 types of detailing. The comparisons indicate that the 3-dimensional nonlinear finite element method using the microplane model (MASA3) can reasonably simulate the behavior of all 3 testing link slabs. Hence, this method could be a numerical tool to study the behavior of link slab under the boundary condition associated with the true-scale test which is more expensive and time-consuming. And the results would be the principal parameters for further design approach.

1. Introduction

Most of highway construction are now prefabricated construction comprising precast members, fabricated on site and then provide cast-in-situ slab deck on site. In recent years, expansion joints have been eliminated to reduce its number throughout total length of overall construction especially for new bridges. The joints can be eliminated by providing continuous deck as which girders can still be simply support and the joint can be eliminated by proper measures to encounter among complicated interactions in the region. The section of the deck connecting the two adjacent simple span girders is called link slab.

The criteria of providing link slab as continuous deck would accommodate all movements into the structure by means of axial deformation, rotation and translation as boundary condition counteract with structural behavior of adjacent spans. Those constraints will be affected not only for principal behaviors but also the secondary stresses due to thermal, moisture, settlement, post-tensioning, and some others. Those conditions are complex in the behaviors which are related to the accuracies and its degree of reliability on strength, serviceability and durability. So the theoretical model to study this problem must be modeled by the boundary condition and cause of link slab. From these effects, the link slab behavior will be non-linear caused by cracking and material properties which must be taken care in the study.

The link slab is assumed to be flexible in comparison with end stiffness of the girders. Both ends of the slab are subjected to vertical and longitudinal movement due to the modulus of elastomeric bearing pad and also subjected to longitudinal and rotational movement due to girder movements.

2. Finite element program MASA

2.1 General

The program MASA has been developed by Josko Ožbolt at the Institute of Construction Materials, University of Stuttgart. MASA is an abbreviation of Macroscopic Space Analysis. The finite element code of MASA is based on the microplane model, and possible to apply to 2-dimensional and 3-dimensional analysis of quasi-brittle materials[1]. The smeared crack approach is employed and the constant stiffness method (CSM) is applied as a root finding method. Furthermore, the crack band approach is used in order to be independent of mesh dependency. Reinforcement is modeled by an uniaxial elasto-plastic stress-strain relationship with or without strain hardening. Time effects such as creep and shrinkage of concrete and other materials can be simulated as well. Several research results especially in the field of concrete structures by MASA showed good agreement with actual test.

2.2 Spatial discritisation

Pre- and post processing of the analysis are performed by a commercial program FEMAP[2]. The entire solid elements are modeled by 8 nodes, and reinforcement is modeled by a 2-node bar element.

2.3 Microplane model

The basic concept of the microplane model was published in 1938 by G.I. Tayer and further developed by Bažant, Ožbolt and co-workers[3]. The model is aimed for modeling of damage and fracture phenomena in concrete and reinforced concrete structures loaded under a general 3-dimensional state of stresses and strains. In the microplane model, the material is characterized by a relationship between the stress and strain components on various orientation shown in Figure 2. These planes may be imagined to represent the damage planes or weak planes in the microstructure, such as contact layers between aggregates in concrete. The advantages of the microplane model are as follows[4]:

1. Simple constitutive relationship such that a set of only uniaxial stress-strain curves on the microplanes need to be defined.
2. The model covers the full 3-dimensional range.
3. It is relatively easy to account for the initial anisotropy.
4. It is applicable for any materials.

On contrary, the disadvantages are as follows:

1. It is difficult to estimate the empirical microplane parameters (i.e. 15 parameters).
2. It is computationally expensive.

2.4 Modeling concrete in the program MASA

The modeling of concrete must be based on the strength of cubic solids as stated in the above section. An example of the concrete behavior of the microplane model in comparison to model of an uni-axial compression from Hognestad is described in Figure 3. The microplane model implies that Young's modulus, Poisson's ratio and 12 microplane parameters must be fixed. The nonlinear concrete behavior by the microplane model shows softening behavior. This behavior is one of the most important characteristics of the microplane model.

2.5 Modeling reinforcement in the program MASA

The constitutive law for steel is defined by uniaxial stress-strain law. The model of the reinforcement is a relatively simple relationship as a tri-linear curve shown in Figure 3. The yielding strength f_y, the Young's modulus E, hardening modulus E_h and ultimate strength f_s must be given as parameters for the FE modeling as bar elements. The behavior is the same for compression and tensile.

3. Numerical investigation

3.1 General

The purpose of this chapter is to have a closer look on the behavior of link slab and to reveal the influences on the detailing of reinforcement in link slab due to axial deformation, end rotation movement, end vertical movement (translation) and mid-span loading with fix ended support.

3.2 Numerical model

The numerical model is shown in figure 4. As mentioned in the last section, concrete is modeled with solid elements and reinforcement is modeled with bar and beam element. Taking the symmetry into account, only ¼ of the specimen has to be modeled. But the end vertical movement model is taken ½ of the specimen. For the boundary of each model and the concentrated load of the mid-span loading model, a loading plate is implemented and the loads are applied at each node of that plate. Furthermore, the elements of the loading plate are assumed to be linear elastic in order to avoid local failure of the concrete.

3.3 Results

The numerical results from different detailing of link slabs under the actions of axial deformation, end rotation, translation and mid-span loading considering cracking behavior are shown in the form of crack pattern and load-deflection relationship as shown in figure 5 and 6. In each reinforcement detailing under the actions, it shows different cracking orders, crack patterns and load-deflection relationship.

4. Experimental studies

The behavior of link slab under cyclic loading was observed for crack distribution, crack width, load-deflection relationship and ultimate strength through experimental work considering variable length of lap reinforcement which can be classified to 3 types of detailing.

4.1 Test Specimens

In order to study the influence of reinforcement detailing, 3 RC link slab specimens were tested. The specimens were designed to be possible for construction with a span of 2,000 mm and slab thickness of 200 mm (Figure 4). The support of link slab is designed to be fixed because the stiffness of girder is much more than stiffness of link slab and it is designed to be produced both positive and negative moments in link slab in order to simulate the behavior of link slab which has to resist both moments. The length of lap reinforcement was parameters in this test and the specimens' detailing and name were shown in Figure 4. The link slab specimens were tested under point load which is applied using a survo-pulser multi-jack actuators of 100 tons capacity. The load is transmitted through a rectangular steel plate of size 50 cm x 20 cm x 2 cm to the link slab in order to represent the AASHTO HS20-44 standard truck wheel load.

4.2 Materials

In this study, ready-mixed-concrete was used and the characteristic compressive strength of concrete is 300 ksc. The used reinforcements were DB16 and DB20 of which yield strength were 4000 ksc.

4.3 Test procedure and Measurements

The overview of the test setup is shown in figure 7. Electrical resistance strain gages of length 0.5 cm are fixed across the mid section and edge section of link slab on both top and bottom reinforcements in order to measure the tensile and compressive strains. Out-of-plane deflections at three points along the mid-section, at one-sixth span and at supports are measured by using linear variable deflection transducers (LVDT). During testing, LVDT, load cell and strain gauges signals were input to a computerized data acquisition system.

The specimens were initially loaded gradually up to 1 ton and then the load is released in order to ensure the loading edges remained in proper contact with the specimen. Then the specimens are cyclic loaded in the first range before and after cracking to observed cracking load and tension stiffening behavior. Next, they are loaded from zero to 9.3 tons and released back to zero and repeated the cycle five times in order to establish a base line curve. The 9.3 tons load represents the factored load for the AASHTO standard HS20-44 truck wheel load (7.1 tons + 30% for impact). Finally they are loaded to failure.

4.4 Results

The first cracks of all specimens were flexural cracks which occurred at supports and mid span. Figure 8 shows the crack patterns and failure modes of all specimens. Figure 11 shows the relationship between mid-span load and vertical displacement of link slab specimens. In the figure, it could be confirm that the detailing of link slab affected the stiffness, crack distribution, crack width. The magnitude of the stiffness was increased as the amount of reinforcement in the specimen was increased and force distribution of structure. The load-deflection relationship and crack distribution from 3-dimensional nonlinear finite element method using the microplane model (MASA3) and true-scale testing could be compared as shown in figure 8-11.

5. Conclusions

In order to investigate the influences of the detailing of link slab for highway girders, 3-dimensional nonlinear finite element analysis is performed. The microplane model according to MASA reasonably simulates the behavior of all 3 testing link slabs both load-deflection relationship and crack distribution. It can be seen that the numerical results obtained in terms of load-deflection relationship and crack distribution agree well with the test results of 3 link slabs. Hence, this method could be a numerical tool to study the behavior of link slab under the boundary condition associated with the true-scale test which is more expensive and time-consuming. The results would be the principal parameters for further design approach.

6. Acknowledgement

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7. Reference

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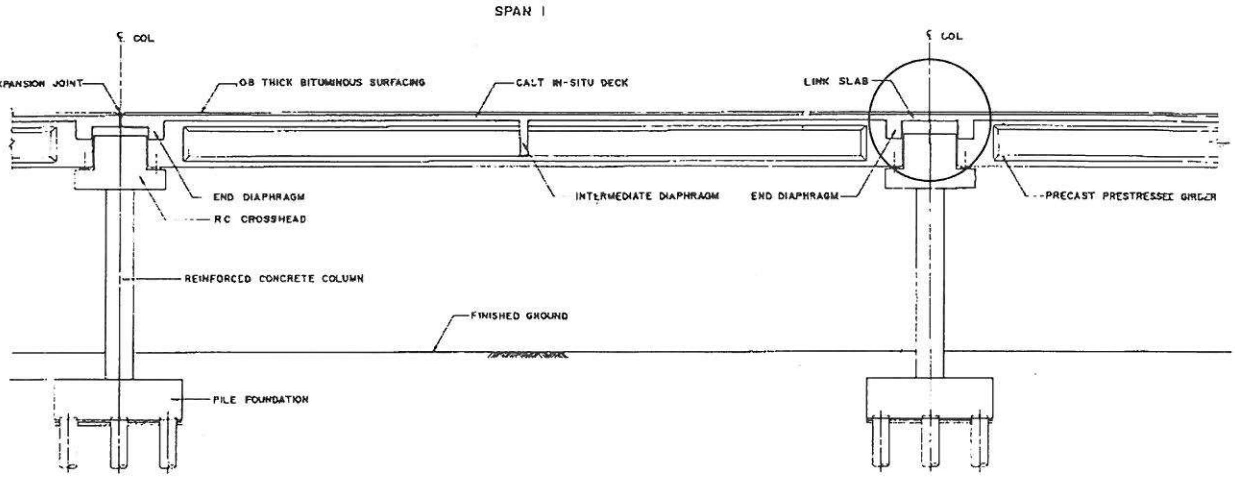
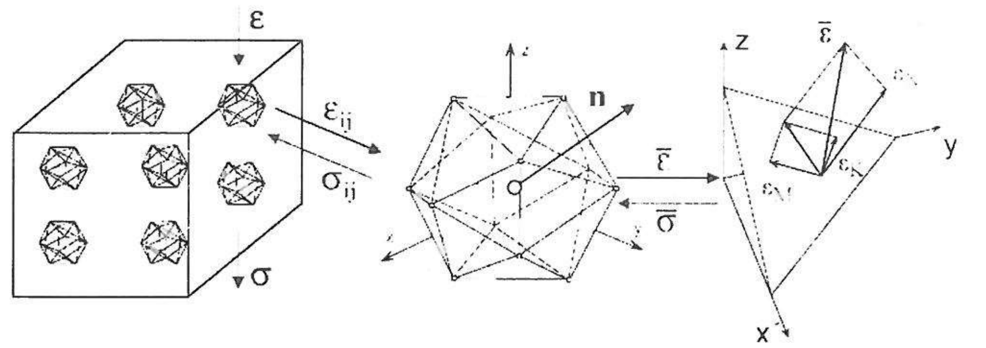


Figure 1 Link Slab



3D solid FE (8 integration points) Integration point Microplane

Figure 2 Microplane Model

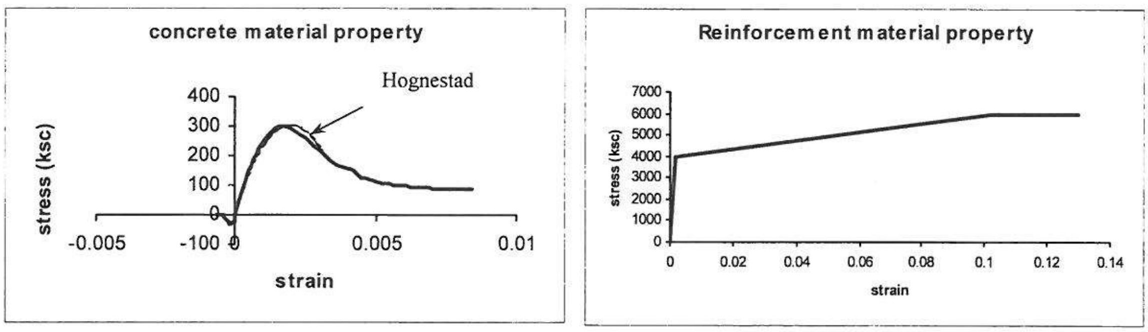


Figure 3 Stress-strain relationship of concrete and reinforcement

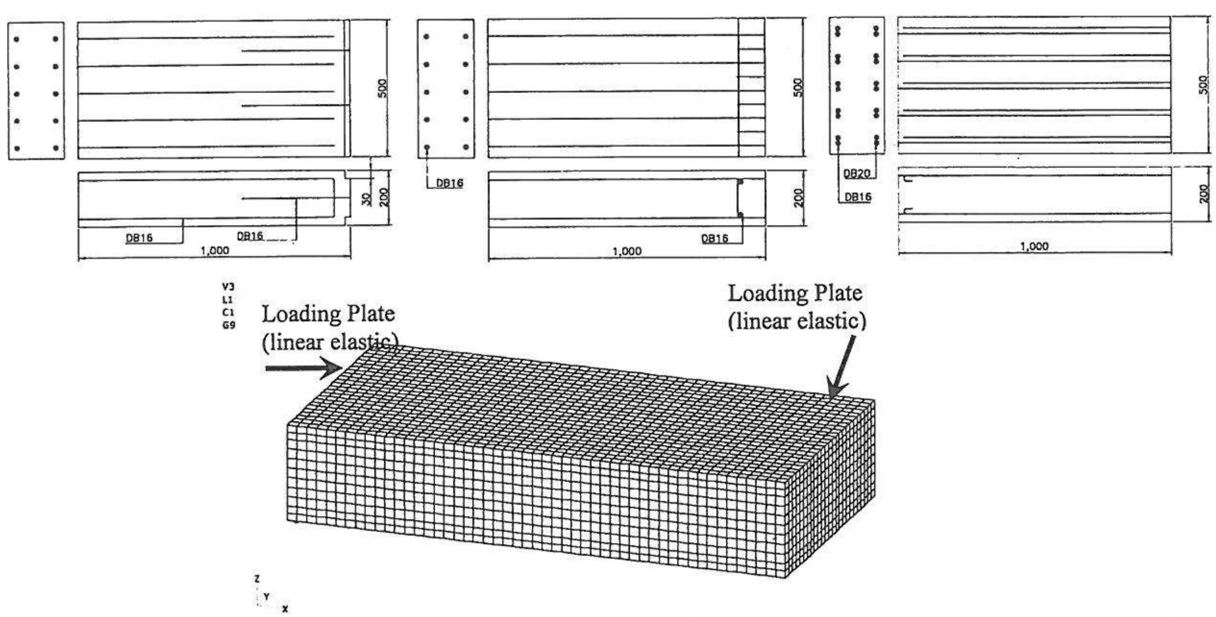


Figure 4 Reinforcement detailing of specimens: LS_000_S, LS_025_S, LS_183_D and Numerical model of link slab specimen with 3 different reinforcement detailings (quarter specimen)

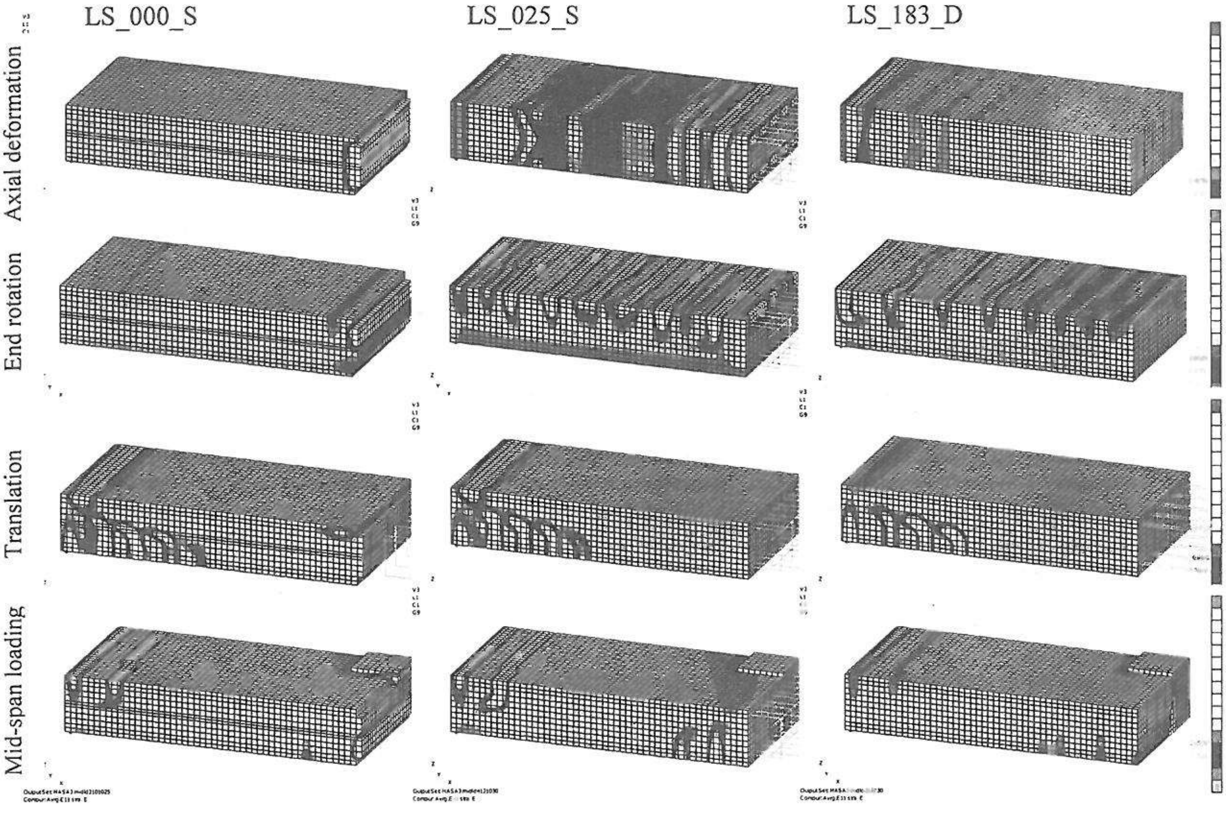


Figure 5 Some outputs from MASA program

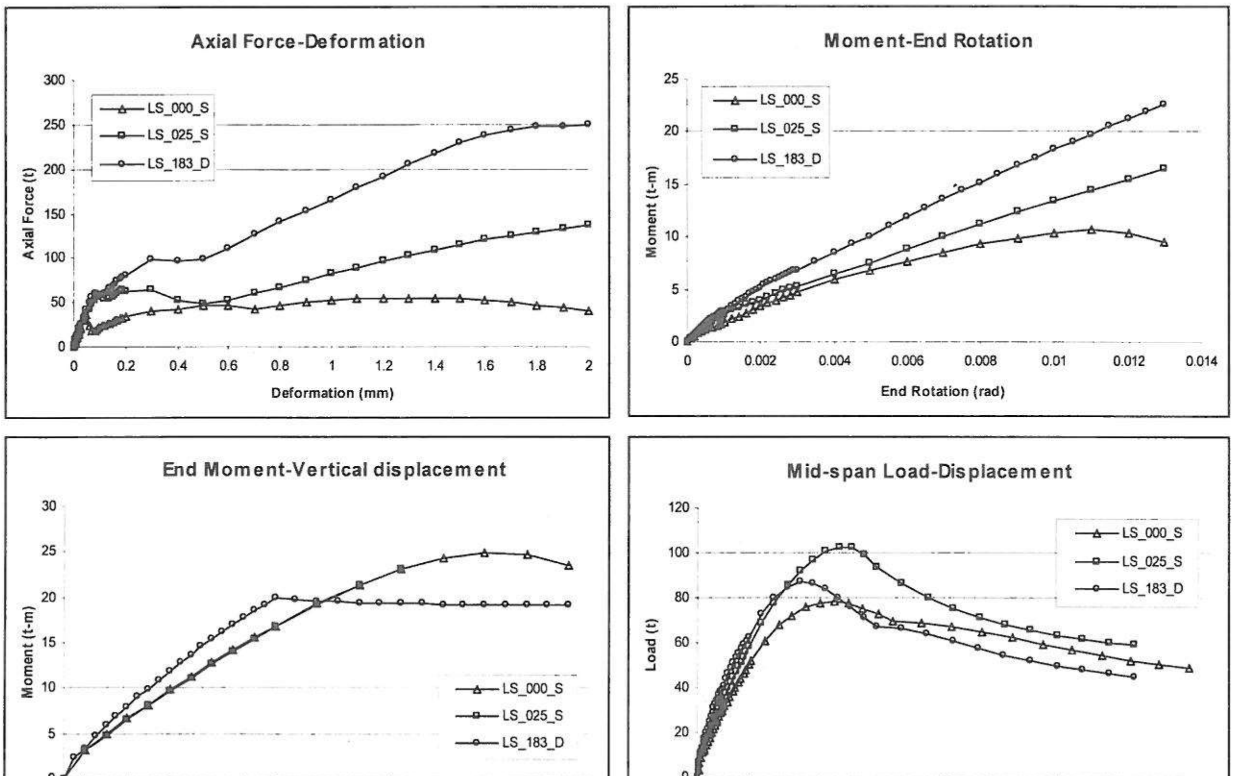
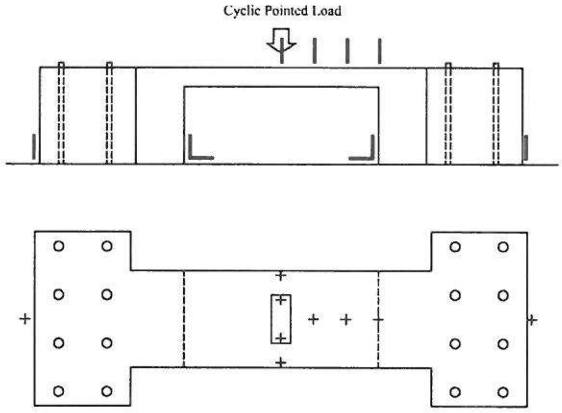


Figure 6 Load-Displacement diagram



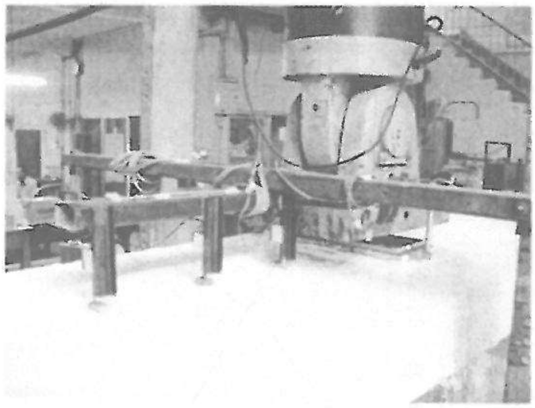


Figure 7 Test specimen (LVDT and load arrangement)

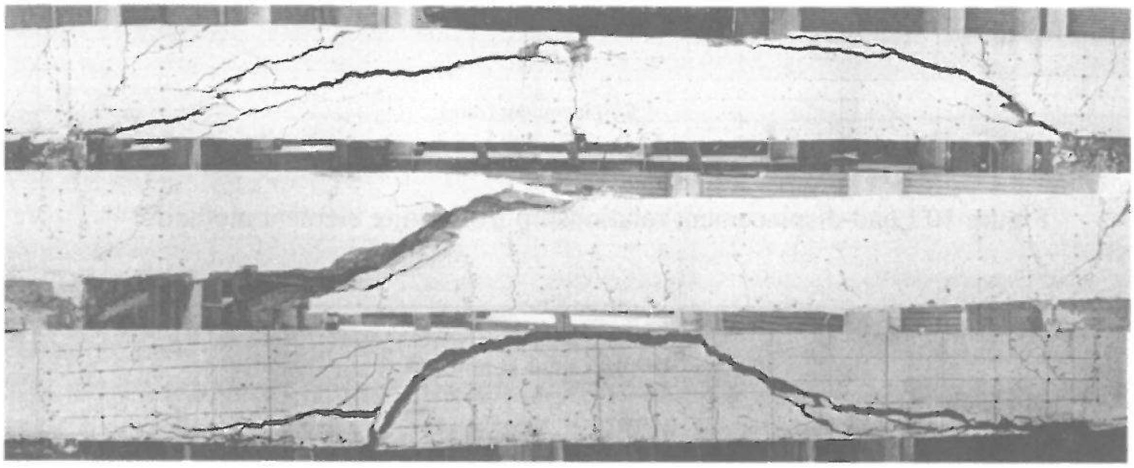


Figure 8 crack pattern and failure mode of LS_000_S, LS_025_S, LS_183_D

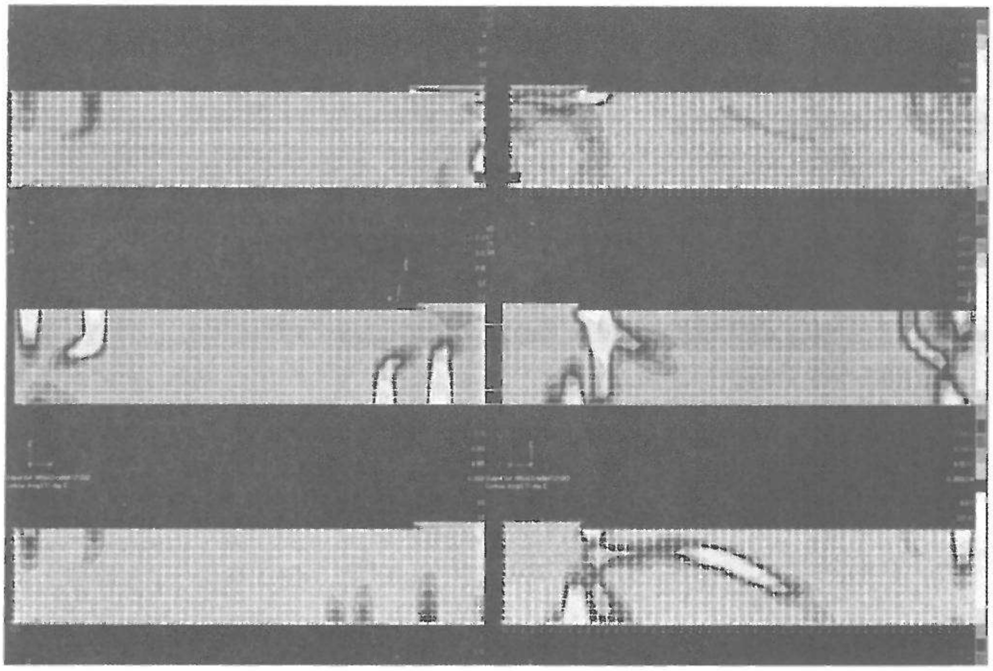


Figure 9 Crack pattern before failure (left) and at failure (right) of LS_000_S, LS_025_S, LS_183_D

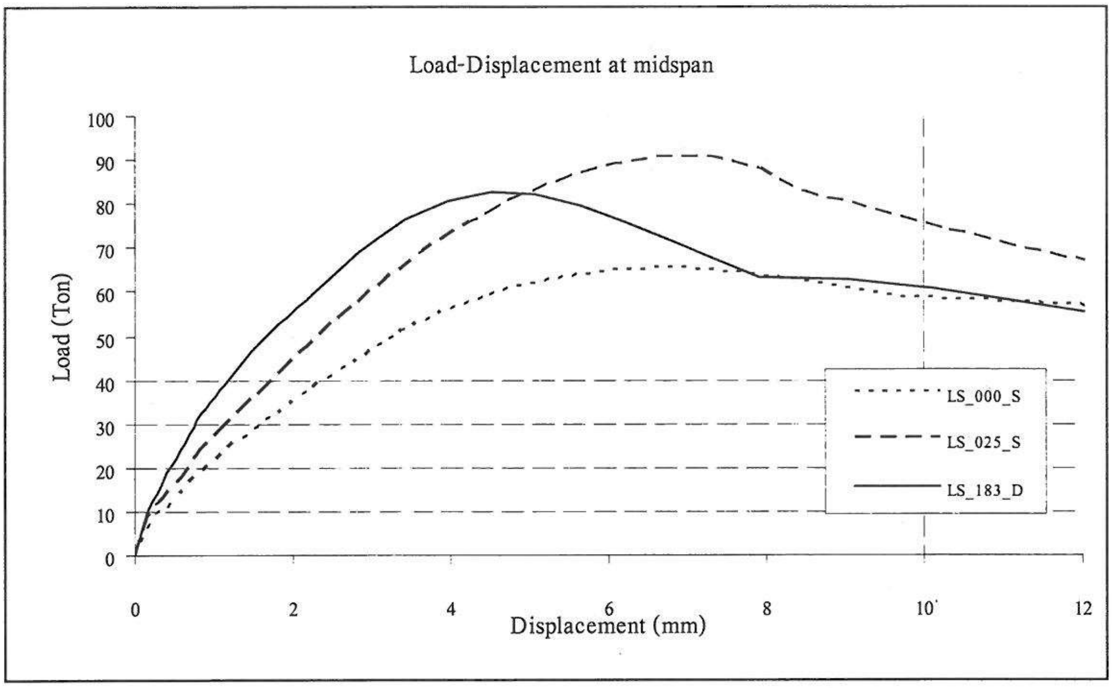


Figure 10 Load-displacement relationship from finite element method

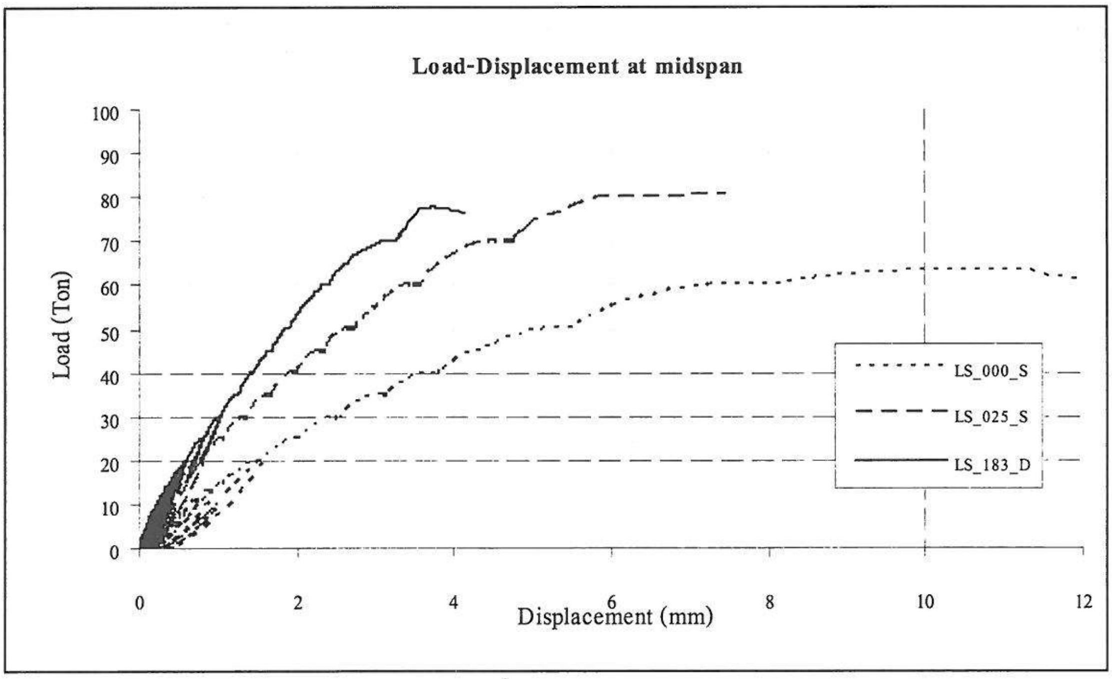


Figure 11 Load-displacement relationship from testing