STRAIN BASED DAMAGE EVALUATION OF CONCRETE ELEMENTS OF A STEEL-CONCRETE COMPOSITE DECK SUBJECTED TO FATIGUE LOADING

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1. INTRODUCTION

Fatigue analysis in Steel-concrete decks have been verified experimentally and analytically, however it is still a challenge to estimate the damage condition in the concrete elements. An evaluation[1)] based on the Drucker-Prager criteria (stress invariants) was conducted to identify areas of high stress concentration at a cross section mid-point of the slab beneath the tyre location considering a fatigue loading of 8 times the T-Load. It was reported that 1) most elements in the top layer were subjected to high compressive stress in excess of 30MPa while at the bottom, elements experienced high tension stress, 2) at the rib region, elements at the top experienced high compression and at the bottom, failure in tension confirmed by the Drucker-Prager yield criterion. 3) at the stud region, elements loaded on the stud head experienced high stress and shear failure was also confirmed and 4) tension failure at the centroid was also confirmed. This report is a strain-based evaluation considering damage indices proposed in the standard specifications for concrete structures (JSCE 2017). This evaluation only considers the concrete section (non-reinforced) beneath the stud head.

2. FINITE ELEMENT ANALYSIS

The analysis considers fatigue analysis using COM3D software. The analysis model (figure 1) is a typical twin girder highway bridge supporting a steel-concrete composite deck of width 6m, 260mm thick concrete slab embedded with reinforcing bars connected to 8mm thick bottom steel plate by headed studs of diameter 16mm. Material strengths for concrete (f_{ck} = 30MPa & f_t = 2.22MPa) and steel (bottom plate & studs, f_y = 245MPa & Rebar, f_y = 295MPa) were applied.

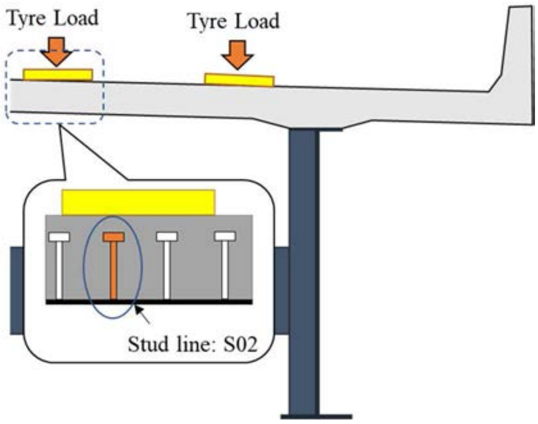

Fig. 1: Analysis model showing area of evaluation

3. DAMAGE EVALUATION IN 3D SPACE

3.1 Invariant Deviatoric Strain and Strain Energy

The local strain at element integration points obtained from the finite element analysis are used to calculate the second invariant deviatoric strain (Equation 1). The strain energy evaluation uses the local stress and strains to calculate the cumulative strain energy (Equation 2).

$$\sqrt{J_2{}'} = \sqrt{(\tfrac{1}{6}((\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2) + (\varepsilon_{xy}{}^2 + \varepsilon_{yz}{}^2 + \varepsilon_{zx}{}^2))} \quad (1)$$

$$W_n = \frac{1}{f_{ck}} \sum_{k=1}^{n} \left[\sigma_x * \delta\varepsilon_x + \sigma_y * \delta\varepsilon_y + \sigma_z * \delta\varepsilon_z + 2(\tau_{xy} * \delta\varepsilon_{xy} + \tau_{yz} * \delta\varepsilon_{yz} + \tau_{zx} * \delta\varepsilon_{zx})\right]^{(k)} \quad (2)$$

3.2 Damage Index

An averaging method of evaluation[2)] for the invariant deviatoric strain ($\overline{\sqrt{J_2{}'}}$) and strain energy ($\overline{W_n}$) based on index $\overline{D}$ in Equation 3 was applied. This reduces the effect of element division on response values at focus cross section for elements within a sphere of radius, r = 150mm (Figure 2). Specific limits for RC members have been set i.e. damage index $\overline{\sqrt{J_2{}'}}$= 0.001, beyond which diagonal cracks and opening of flexural cracks begin to manifest. Additionally, concrete is known to crush when damage index $\overline{W_n}$ exceeds 0.0015.

$$\overline{D} = \frac{\int_v D * w(s)dV}{\int_v w(s)dV} \quad (3)$$

Where

$$w(s) = \begin{cases} 1 - s/r\,, & (s \le r \\ 0, & (s > r) \end{cases}$$

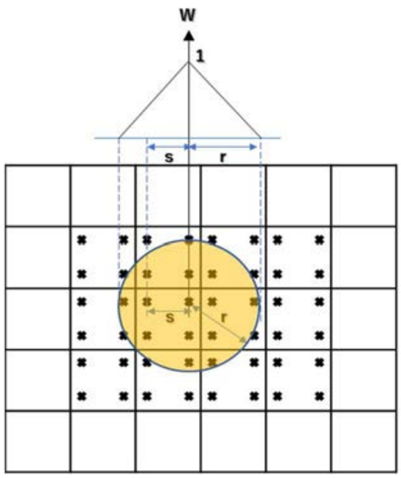

Fig. 2: Weighting criteria

Keywords: Invariant Deviatoric Strain, Strain Energy, Damage Index, Fatigue Analysis, Steel-Concrete Composite Slab
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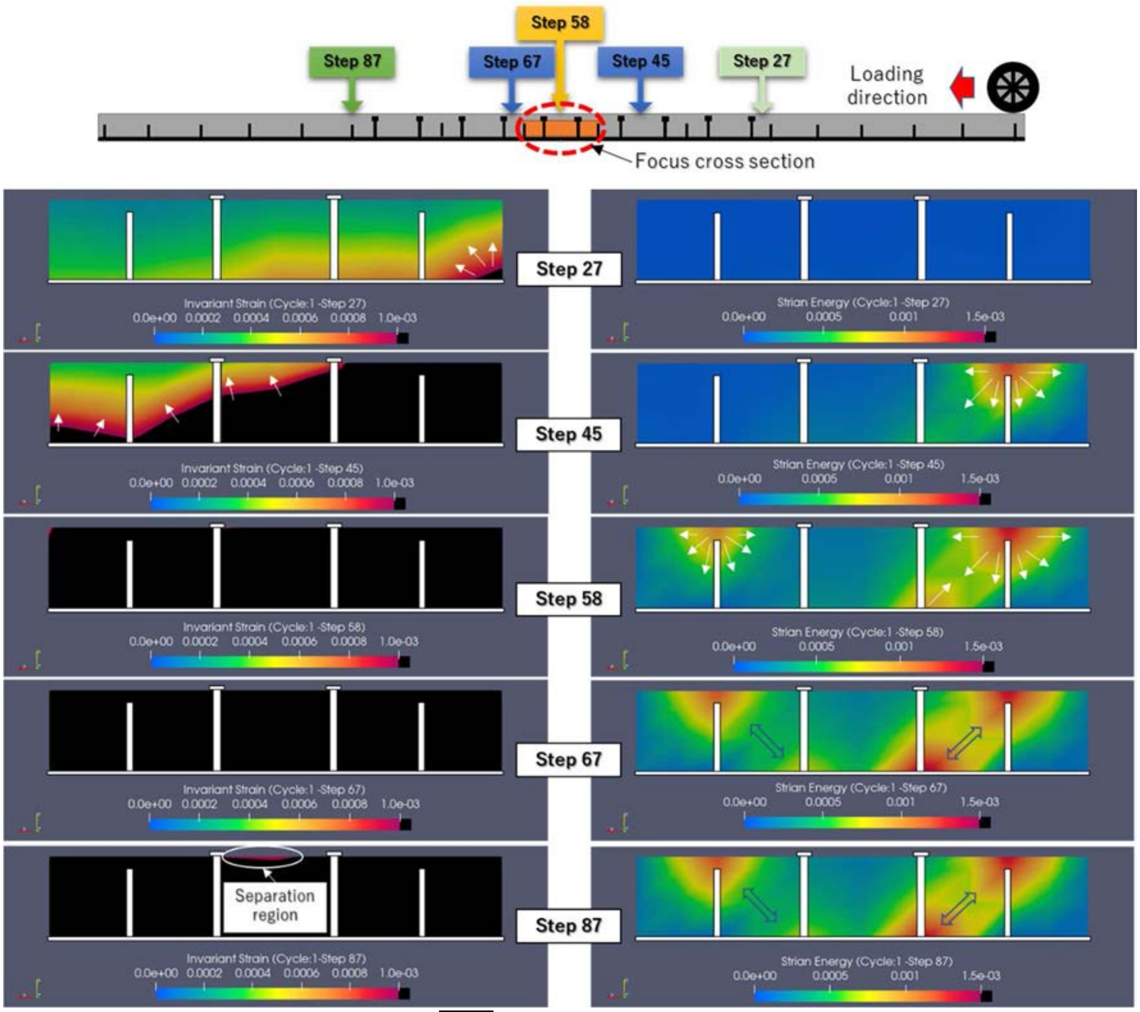

a) Invariant deviatoric strain ($\sqrt{\boldsymbol{J_2}'}$) b) Strain Energy ($\overline{\boldsymbol{W_n}}$)

Fig. 3: Damage Index distribution across focus cross section at different loading steps during the first loading cycle

4. RESULTS AND DISCUSSION

Damage progression at the focus cross section considering loading steps as indicated on Figure 3 are discussed below.

1) Damage index, $\sqrt{J_2'}$: at step 27, damage index development starts at the bottom and progresses towards the upper layers as load tends towards step 45 due to punching shear effect. Between step 58 and 67, the damage index is more than 0.001 due to high deformation at the slab centroid region. At step 87, at the concrete portion between the stud, there is a possibility of separation of concrete into two layers.
2) Damage index, $\overline{W_n}$: possibility of concrete crushing starts as the load approaches rib region on the left due to high compressive stress. Towards the center of the slab (step 45 to 58), damage index progression is observed at the bottom of the right-hand stud and also at the top of the rib at the left-hand side of cross section. Between step 67 and 87, while damage doesn't seem to increase on the left-hand side, there is a gradual increase on the left-hand side at the top of the rib and bottom of the stud. Additionally, there is no significant strain energy development beneath the stud head region regardless of the loading position thus insignificant damage implied. However, the contour figure indicates that there is a diagonal relation of the damage index at the bottom of the stud and at the top of the nearest rib.

5. CONCLUSISON

The results show damage as a result of crack opening and development of diagonal cracks occurs instantly in the first loading cycle as the load arrives the centroid of the slab due to the heavy loading that causes excessive slab deformation. Additionally, there is progressive crushing of the concrete that occurs at the top of the rib and bottom of the stud. However, to fully grasp the damage mechanism, it is recommended that more loading cycles be examined.

REFERENCES

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