Mechanical Response of Voiding Cement Pavement under Load

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Abstract. An FEM model was built to analyze mechanical response of various load transfer capacities and various voids. Typical models, including 2, 4, 6 and 9 pieces, were modeled in order to analyze stress and deflection of the pavement slabs. Effect of various factors was discussed and compared as well. The conclusions of this paper supply accordance to cement pavement design and a guide for pavement testing and maintenance.

1. Introduction
Void under cement slabs is a typical defect of pavement engineering. It effects the performance of pavement structure a lot when the void was developing. It also increases the stress and deflection and decreases the operating life. During the early time of the void, the support of base for the pave layer decreases as well as the response modulus. When the void develops, the base and the pave disengages and the support between both layers was lost. The mechanism of such a voiding pavement is like a cantilever beam and increases the possibility of structural damages. What’s more, the process of voiding is permanent and unrecoverable. However, several measures can be conducted for the remission of the defect. This paper was mainly focused on the mechanical response of cement pavement slabs. An FEM model was built in order to analyze the characteristics of stress and deflection. The result of this research supplies an accordance to the design and maintenance of cement pavement.

2. An FEM model of a voiding cement pavement
The software ABAQUS was used in this paper in building the FEM model. ABAQUS was a commercial software developed by Hibbitt, Karlsson & Sorensen Company, which can be applied in structure modeling. ABAQUS is good at solid mechanics and structure mechanics. It also can deal with the nonlinear problems. On Constitutive Models, a theory for thin elastic plate was used in calculating the deformation. The relationship between deflection and stress was revealed according to Winkler model. On load transfer capacity, a thin lift of material at the joint was manifested and both sides of the thin lift were tied together. In that, the load transfer capacity can be regulated by a change of modulus of the material.

Fig.1 The virtual material in the joint
ABAQUS supplies all kinds of element types, the users can choose the best element type and net divide. Theoretically, it is better to use the highest class of element that may cost a lot of time in calculating. So a balance should be considered between the accuracy and efficiency. According to recent research, a half thickness of the slab, which varies from 34cm~44cm, may be a proper density of the net elements. So we choose 10cm as the thickness in this paper and the type of element is C3D8I, which can get a second class accuracy. A square distributed loading was applied, of which the value is 1.98Mpa. The cement pavement is usually made with regular square slabs and the dimension is 5m×5m. In order to modelling the real loading condition, various mode including 2, 4, 6, and 9 slabs was calculated for a proper accuracy. And it was concluded as follows: the 4 slabs model brings to a good accuracy for the calculation of loading at the middle position as well as the corner position. The 2 slabs model brings to a good accuracy for the calculation of loading at the edge.

| The Layers | Index          | Value |
|-----------|---------------|-------|
| surface   | Slabs/piece   | 2, 4, 6, 9 |
|           | Dimension/m×m | 5.0×5.0 |
|           | Bending strength/MPa | 5.0 |
|           | Bending elastic modulus/MPa | 36000 |
|           | Poissons ratio | 0.15 |
|           | Thickness/cm   | 40    |
| joint     | Modulus/MPa    | 600   |
|           | Poissons ratio | 0.3   |
| subgrade  | Modulus/ (MN/m³) | 80 |

According to the normal patterns of voids, the void at middle was settled as an oblong and the one at corner was settled as a square. Three types of models, including middle, edge and corner, were considered also (fig.2). The length of the oblong void was 5.0m and the width was 0.3m. The length of the square void was 1.5m. In order to modeling the decrease of strength of voiding base, a modulus reduction was used in calculation on the top of the base layer. The reduction of K varies from 1.0, 0.7, 0.5, 0.3, and 0. The response modulus was made of a multiplication of K and the modulus of the top base layer. When K=1, there is no void. When K=0, there is a complete void.

![Fig 2. The patterns of the voids](image)

3. Analysis of stress of the voiding slabs
Stress response of various types of voids was calculated with the FEM models above. The thickness of surface was 34cm and three types of models, including middle, edge and corner, were considered also (fig.3).
3.1 Edge voids
As is known from the figures above, the relationship between main stress and K is linear. The voiding degree (reflected by a reduction of K) affects the stress little. In any condition of joint transfer capacity, the stress of complete void (K=1) was 2%~6% more than the result of non-void. Compared with the voiding degree, the joint transfer capacity affects main stress more. In any condition, when the joint transfer capacity varies from good to middle, middle to bad and bad to worst, the main stress increases by 25%, 21% and 10%. When the joint transfer capacity varies from good to worst, the main stress increases by 65%.

3.2 Corner voids
The relationship between main stress and K is almost linear. Affection from voiding degree to main stress depends on the variation of joint transfer capacity. When the joint transfer capacity is good, main stress of a complete void is 10% than the non-void. When the joint transfer capacity varies from middle, bad and worst, main stress increases by 16.9%, 26.6% and 38.2%. The voiding degree affects main stress more when the joint transfer capacity decreases. When the joint transfer capacity is good, the biggest stress happens on the top of the slab. When the joint transfer capacity is worst, the biggest stress happens on the bottom of the slab. When the joint transfer capacity varies from middle to bad, the value of stress is between both, which can be reckoned as a neutralization of both. So the least main stress doesn’t happened when the joint capacity is the best but the joint capacity is middle.

| Reduction of K | middle/good | bad/middle | worst/bad | worst/good |
|---------------|-------------|------------|-----------|------------|
| 1.0           | 25.05%      | 20.99%     | 8.95%     | 64.85%     |
| 0.7           | 25.15%      | 21.36%     | 9.28%     | 65.98%     |
| 0.5           | 25.16%      | 21.68%     | 9.46%     | 66.70%     |
| 0.3           | 25.24%      | 21.92%     | 9.71%     | 67.52%     |
| 0.0           | 25.32%      | 22.38%     | 10.08%    | 68.81%     |

Tab.2 The main stress of corner voids varies from joint transfer capacity

The affection from joint transfer capacity to main stress depends on the voiding degree. The transfer capacity is increasing when the voiding degree is getting worse. On the non-void, when the transfer capacity varies from good to worst, the main stress increases by 25.03%. For the complete void, it increases by 56.23%.

3.3 Corner + edge voids
When there are both voids, the result of main stress is closed with the corner void. So the affection from edge void is very limited and the both voids may be ignored in the actual projects.
4. Analysis of deflection of the voiding slabs

Deflection response of various types of voids was calculated with the FEM models above. The thickness of surface was 34cm and three types of models, including middle, edge and corner, were considered also (fig.4).

4.1 Edge voids

As is known from the figures above, the relationship between deflection and K is linear. When the joint transfer capacity is good, deflection decreases little by the decreasing of K. The deflection increases more when the joint transfer capacity is worse. When the transfer capacity varies from good to worst, the deflection decreases by 7.8%, 12.11%, 17.84% and 25.82, which can be seen apparently in the figures above.

As is shown in Tab.3, the joint transfer capacity affects the deflection a lot. When the transfer capacity varies from good to worst, the deflection decreases by 30%, 40% and 30%. When K is decreasing, transfer capacity is getting worse. When the joint capacity varies from good to worst, deflection totally increases by 121.94%~159.04%, which is much more than the modulus of top base layers (7.8%~25.82%).

| Reduction of K | middle/good | bad/middle | worst/bad | worst/good |
|----------------|-------------|------------|-----------|------------|
| 1.0            | 29.07%      | 36.90%     | 25.60%    | 121.94%    |
| 0.7            | 30.48%      | 38.68%     | 27.65%    | 130.98%    |
| 0.5            | 31.46%      | 40.01%     | 29.21%    | 137.83%    |
| 0.3            | 32.55%      | 41.44%     | 30.89%    | 145.40%    |
| 0.0            | 34.24%      | 43.89%     | 34.10%    | 159.04%    |

4.2 Corner voids

The relationship between deflection and K is linear. Compared with edge void, the deflection increases more when K varies from 1 to 0. When the joint transfer capacity varies from good to worst, the deflection increases by 17.89%, 12.11%, 17.84% and 25.82%. What’s more, the voiding degree affects the deflection more when the transfer capacity is worse.

The transfer capacity affects deflection a lot (tab.4). When the transfer capacity varies from good to worst, the deflection decreases by 73%, 97% and 70%. When the transfer capacity varies from good to worst, the deflection totally increases by 388.04%~615.52%, which is less than the top base layer (17.89%~72.84%) as well as the edge void (121.94%~159.04%).

| Reduction of K | middle/good | bad/middle | worst/bad | worst/good |
|----------------|-------------|------------|-----------|------------|
| 1.0            | 71.01%      | 86.83%     | 52.75%    | 388.04%    |
| 0.7            | 71.85%      | 88.55%     | 63.81%    | 430.78%    |
|   |   |   |   |   |
|---|---|---|---|---|
| 0.5 | 72.51% | 97.59% | 66.61% | 467.90% |
| 0.3 | 73.22% | 103.24% | 74.72% | 515.11% |
| 0.0 | 74.19% | 113.63% | 92.28% | 615.52% |

4.3 Corner + edge voids
When there are both voids, the result of deflection is closed with the corner void. So the affection from edge void is very limited and the both voids may be ignored in the actual projects.

5. Conclusions
An FEM model was built to analyze mechanical response of various load transfer capacities and various voids. Typical models, including 2, 4, 6 and 9 pieces, was modeled in order to analyze stress and deflection of the pavement slabs. Effect of various factors was discussed and compared as well. The conclusions of this paper supply accordance to cement pavement design and a guide for pavement testing and maintenance.

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