Poroelastic modeling of porewater movement and pore pressure development in pavement system

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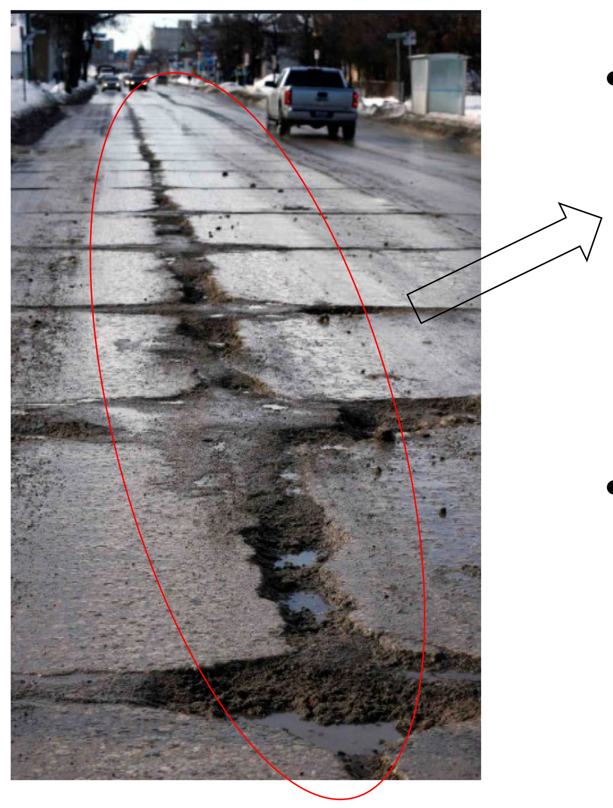
Objectives



- To identify and quantify the traffic-induced dynamic porewater pressure and its effect on pavement mechanical manifestations.
- To optimize the design of moisture resistance of pavement structures to dynamic water pressure induced damage

Figure 1. Moisture induced damage to pavement[1]

Background

- Plenty of sources for water infiltrating pavement layers
- Entrapped water under dynamic traffic loads can develop intense water pressure which can significantly damage pavement structural capacity

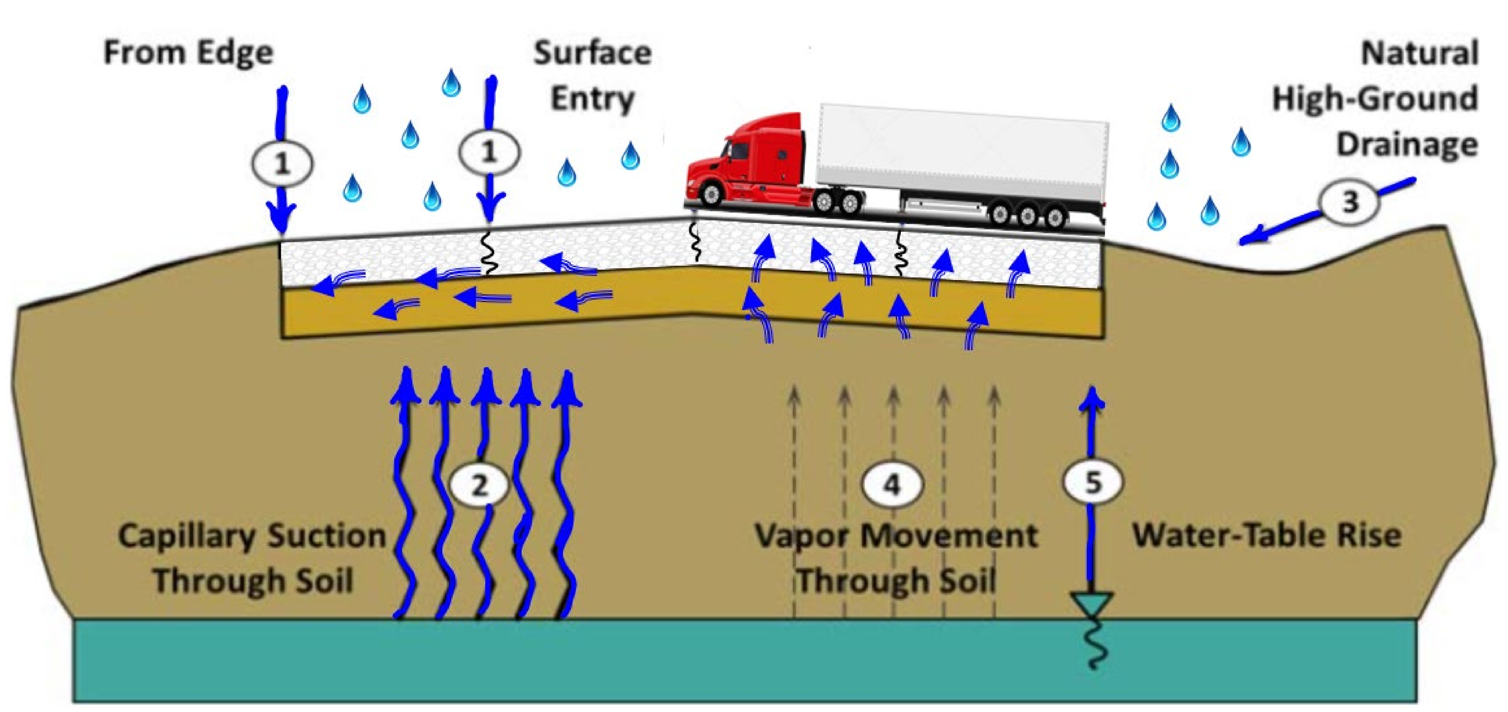


Figure 2. Sources of moisture in pavement

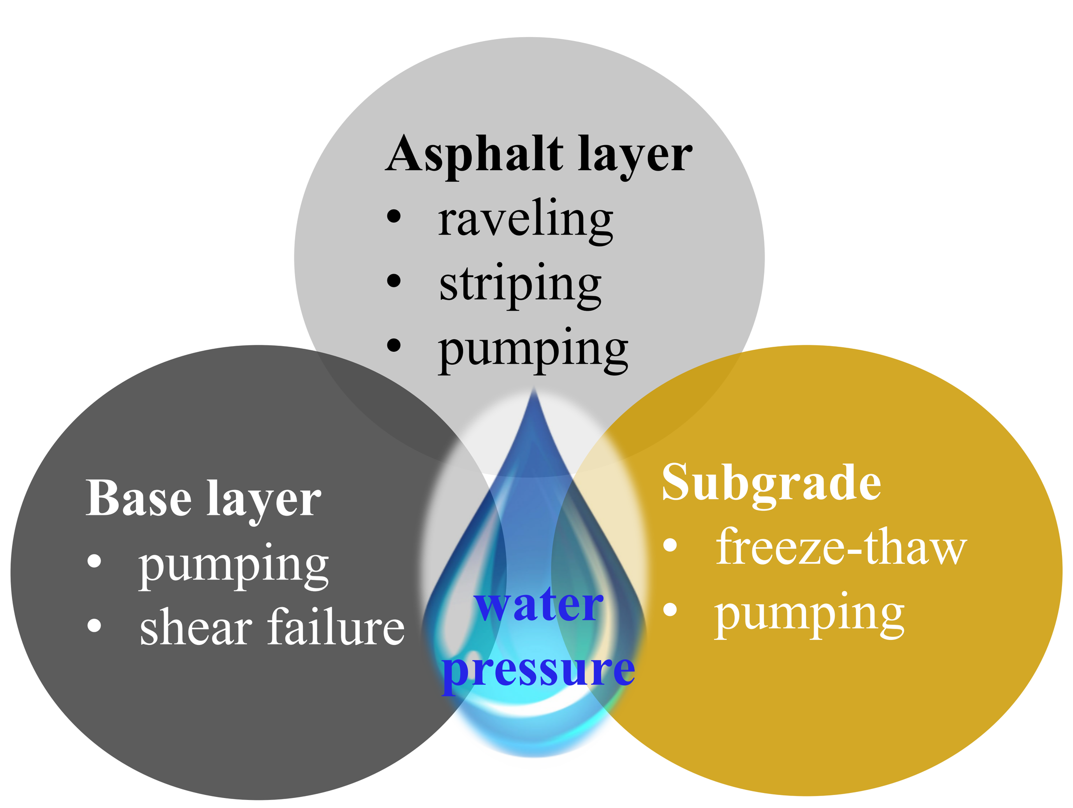


Figure 3. Effect of water pressure on pavement layers

Methodology

- **Program of multi-layer (N-layer) pavement system**

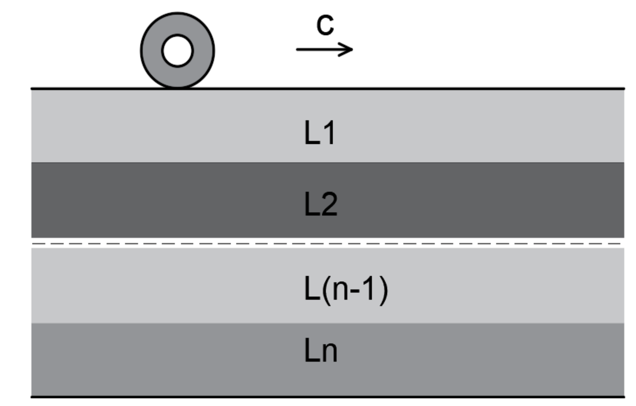


Figure 4. Multi-layer (N-layer) pavement system

- **Governing equations (Biot's Equations[2])**
  - Equation of motion
  $$\sigma_{ij,j} = \rho \ddot{u}_i + \rho_f \ddot{w}_i$$
  - The constitutive relationships
  $$\sigma_{ij} = 2\,\mu\, e_{ij} + \lambda\, \delta_{ij} e - \alpha\, \delta_{ij} p$$
  $$p = -\alpha\, M\, e + M\, \xi$$
  - Darcy's law:
  $$\dot{w}_i = -\frac{1}{b}\left(p_{,i} + \rho_f \ddot{u}_i + m\, \ddot{w}_i\right)$$

u: displacement of soil skeleton **p:** fluid pressure
w: average relative displacement of fluid to soil frame
ξ: variation in fluid content e_{ij}: strains. **α**: Biot's coefficient
σ: total stress in bulk material **1/b**: permeability coefficient

- **Developed computational program - Poroelastodynamic Finite Integration Technique (PEFIT[3])**
- Velocity-stress staggered-grid finite-difference method
- Fourth-order accuracy in space and second-order accuracy in time
- Can be applied on 2D and 3D poroelastic media
  - Stagger velocity vector and stress tensor in space

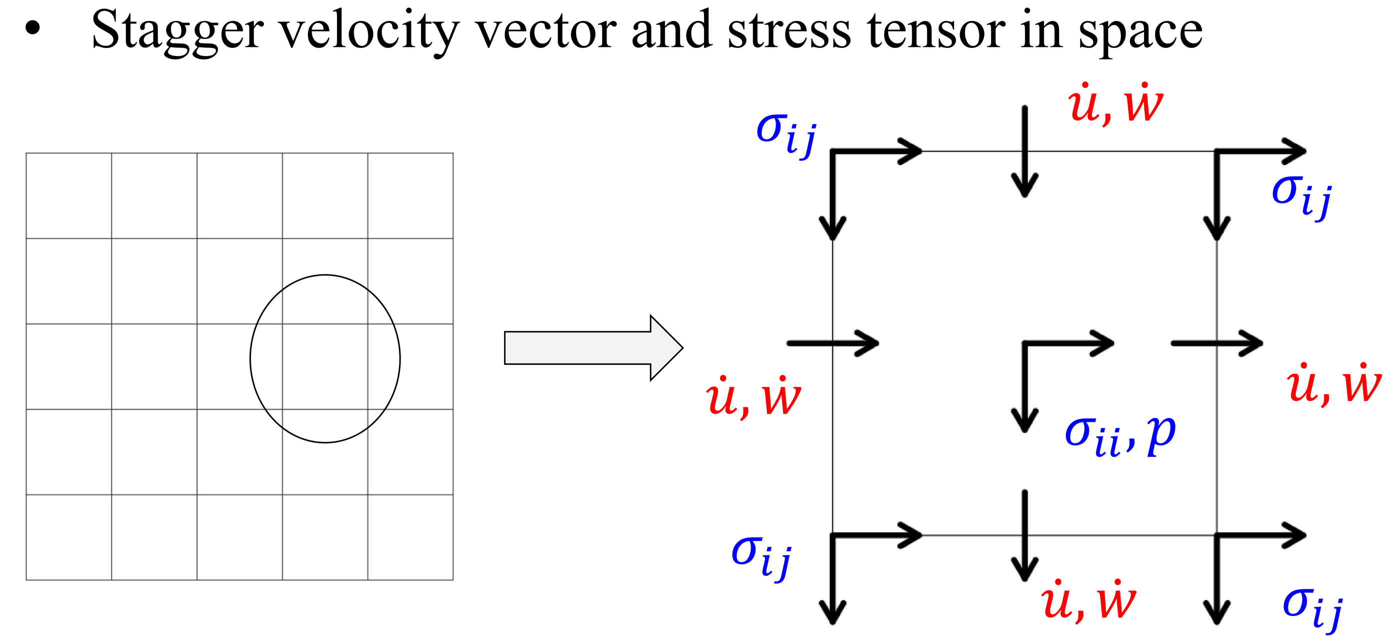


Figure 5. Staggered-grids in space domain

  - Stagger velocity vector and stress tensor in time

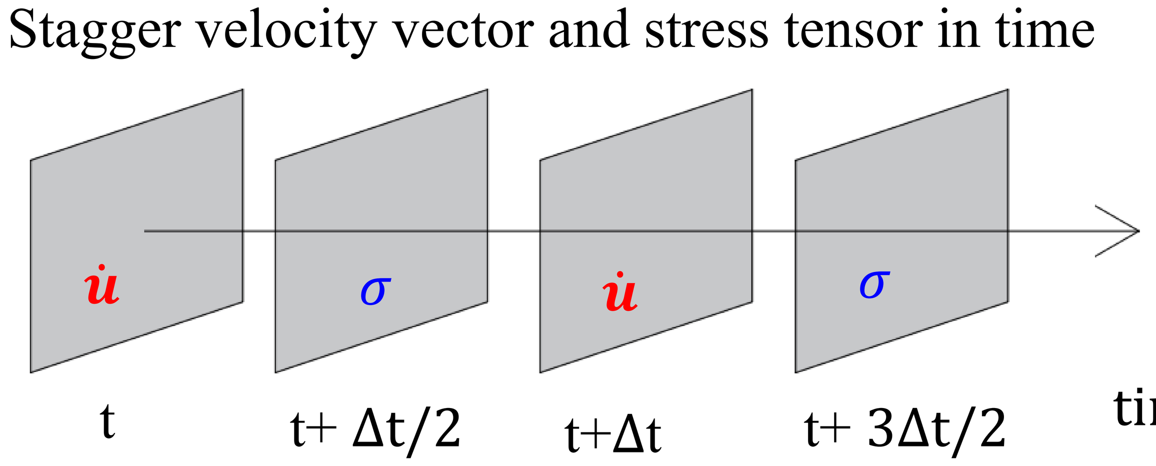


Figure 6. Staggered-grids in time domain

Results

- Concrete layer with crack

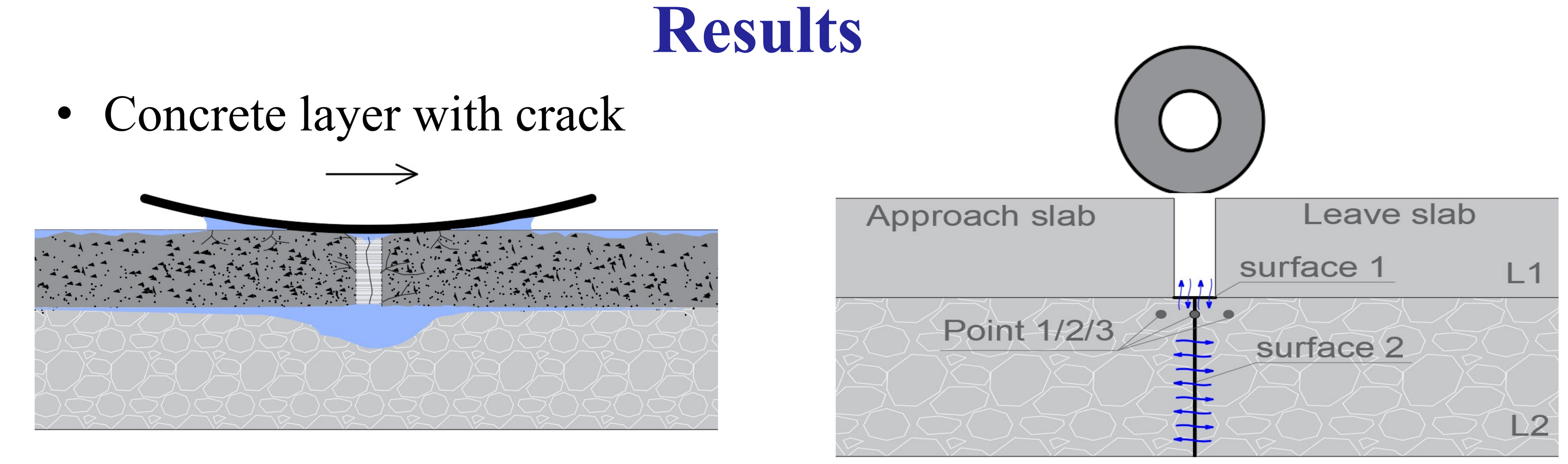


Figure 7. Water fill base layer under traffic load

- Size of model: 1440 x 90. Cell number: 129,600. Plate form: MATLAB

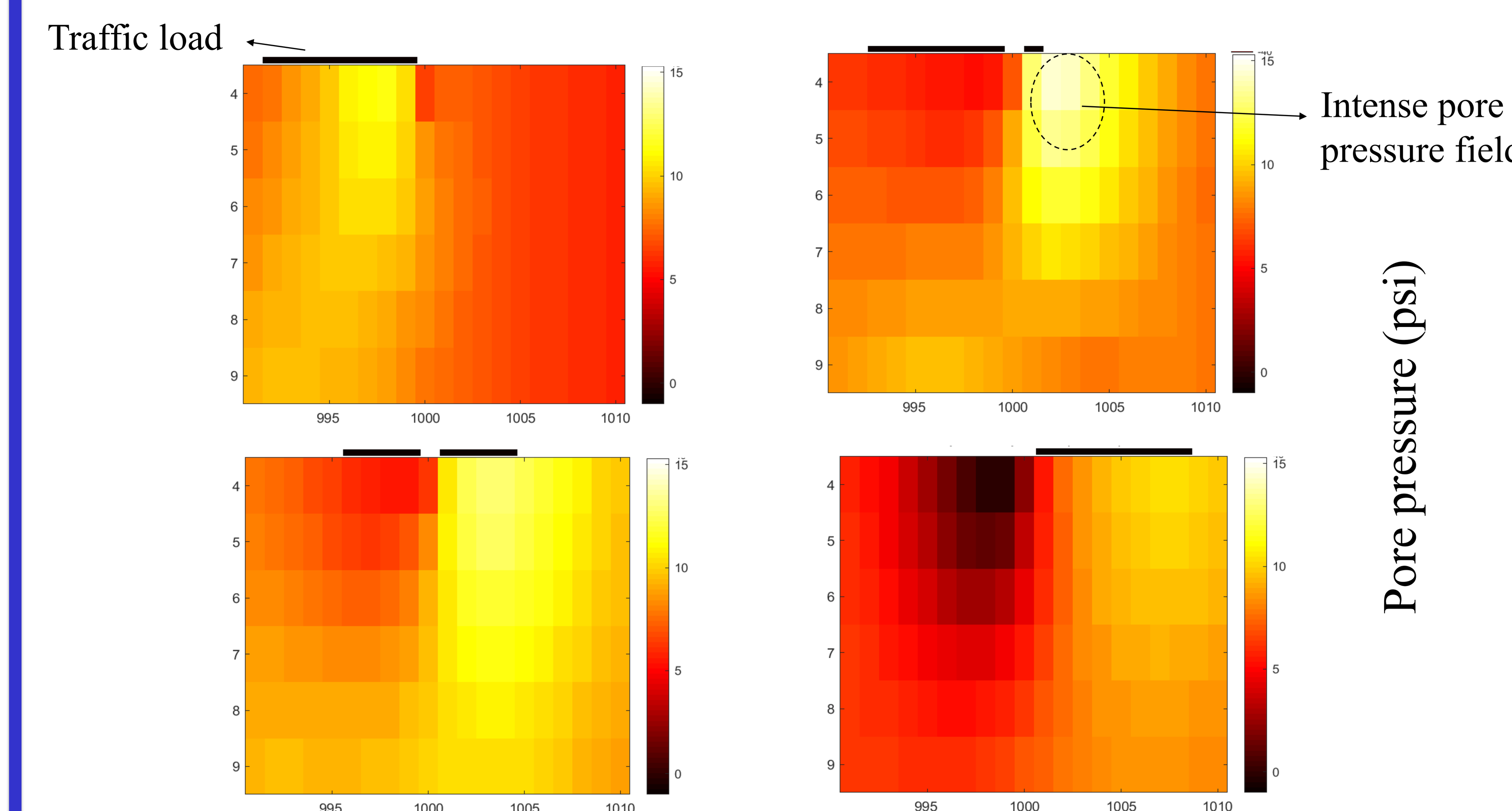


Figure 8. Dynamic pore pressure at critical moments

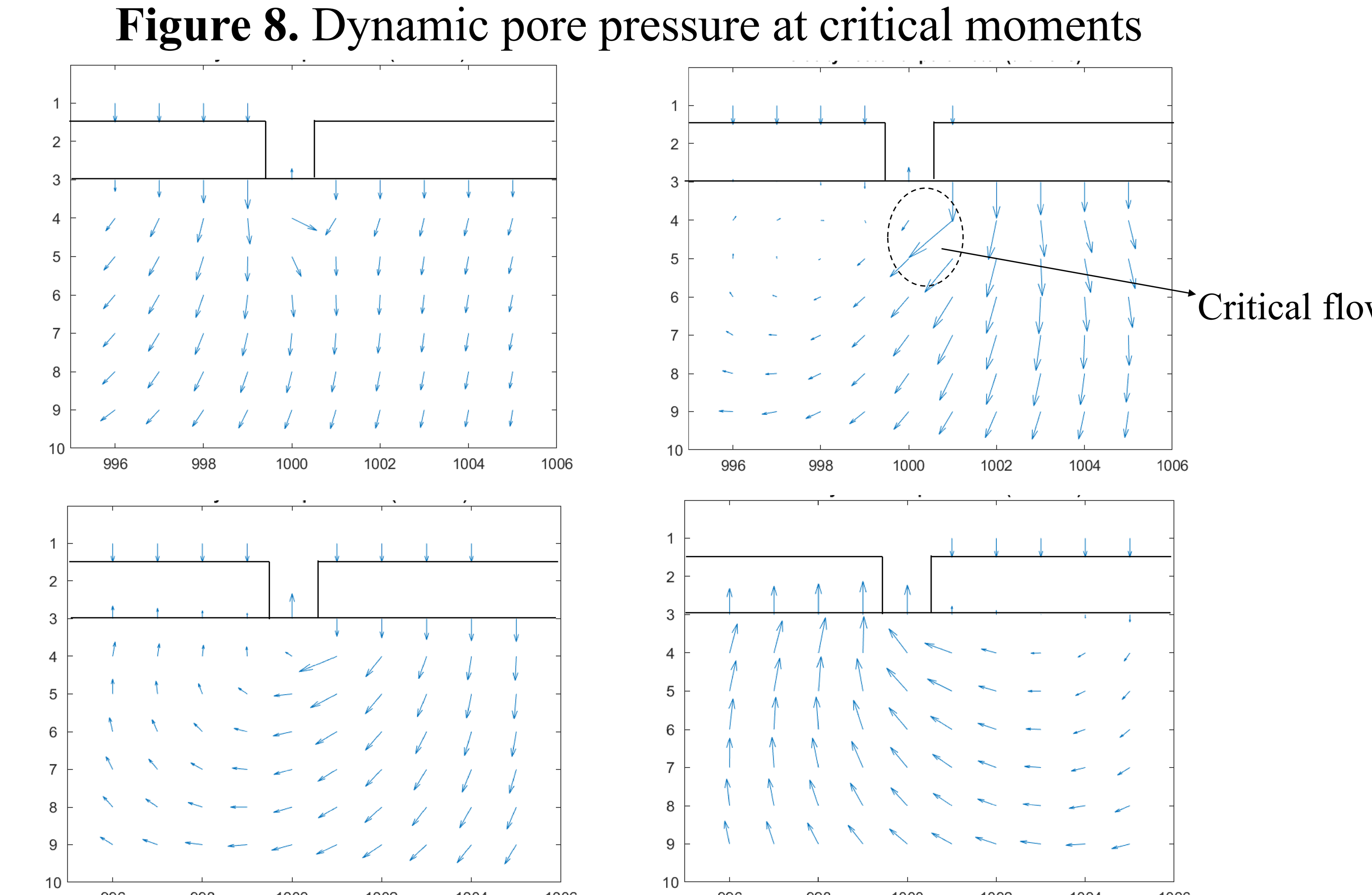


Figure 9. Porewater flow rate at critical moments

Conclusion

- Dynamic pressure development and directional water flow are successfully simulated by the program
- PEFIT is regarded as a promising tool for solving dynamic pore pressure related problems in pavement engineering

[1] Figure 1. retrieve from https://pavementinteractive.org/reference-desk/pavement-management/pavement-distresses/stripping/
[2] Biot, Maurice A. "Mechanics of deformation and acoustic propagation in porous media." Journal of applied physics 33, no. 4 (1962): 1482-1498. eq(3.8)
[3].P. Fellinger, K.J. Langenberg, "Numerical Techniques for Elastic Wave Propagation and Scattering", in: S.K. Dana, J.D. Achenbach, Y.S. Rajapakse, eds., Elastic Waves Ultrasonic Nondestructive Evaluation, North-Holland, Amsterdam (1990) 81-86.

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