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(b) $\phi'=10^\circ$

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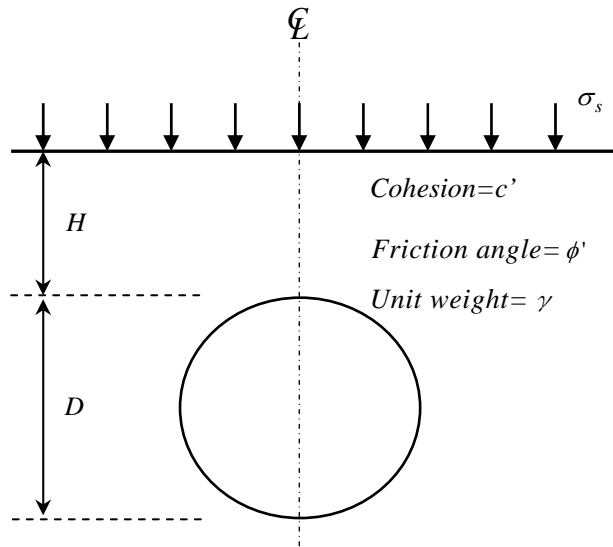
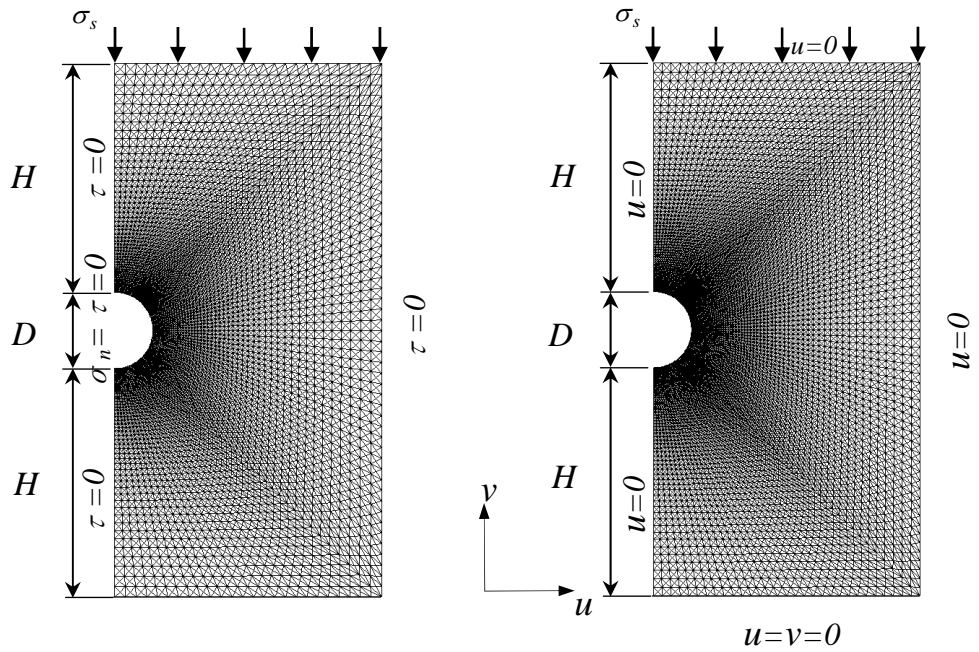
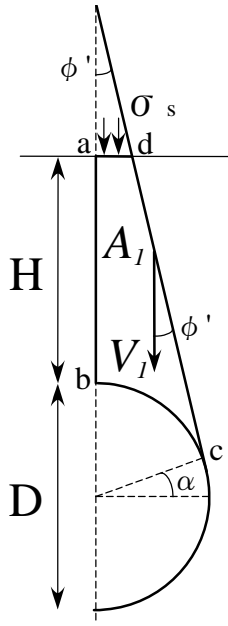


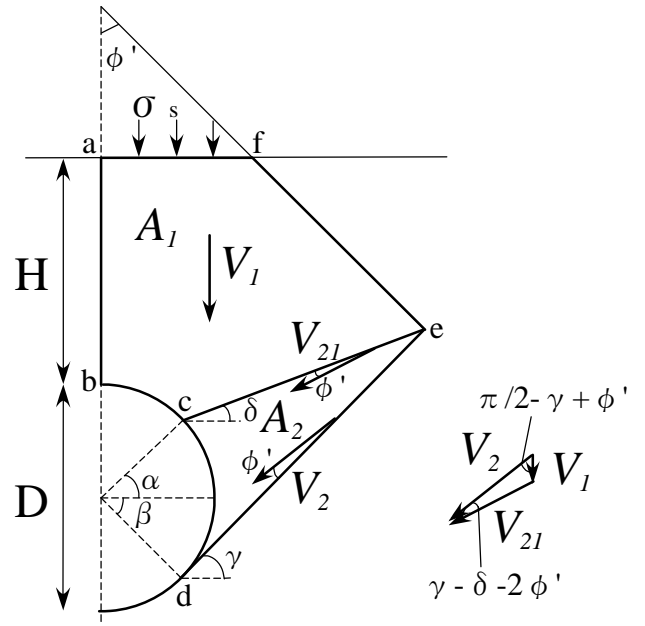
Fig. 1. Plane strain circular tunnel in cohesive-frictional soil.



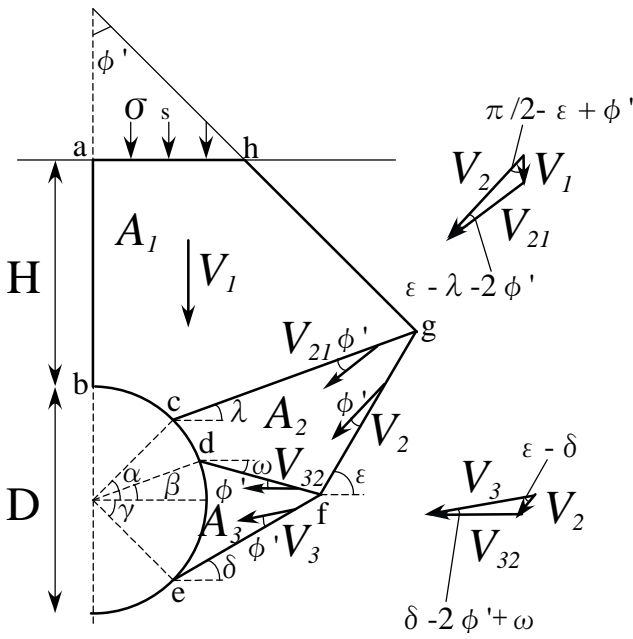
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 Fig. 2. Typical finite element meshes for a circular tunnel ($H/D=3$, rough interface).



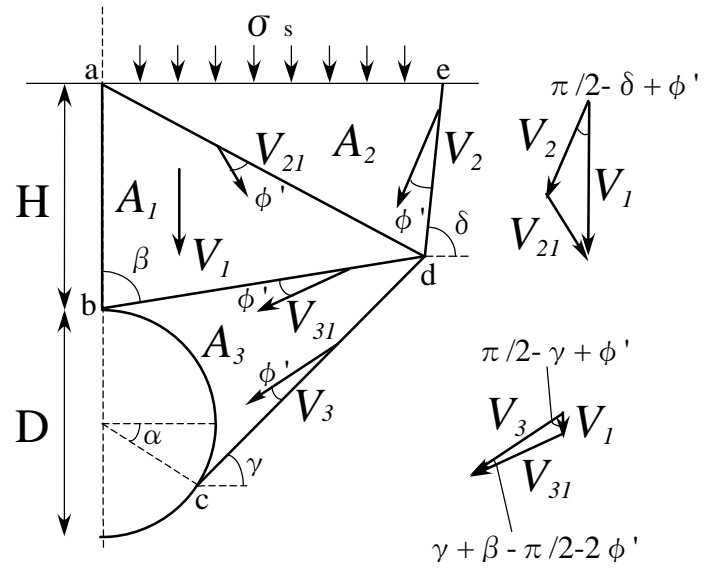
(a) Mechanism 1



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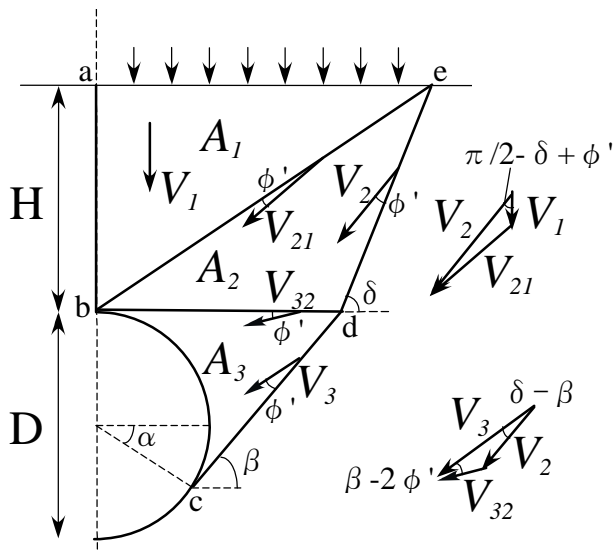


(c) Mechanism 3

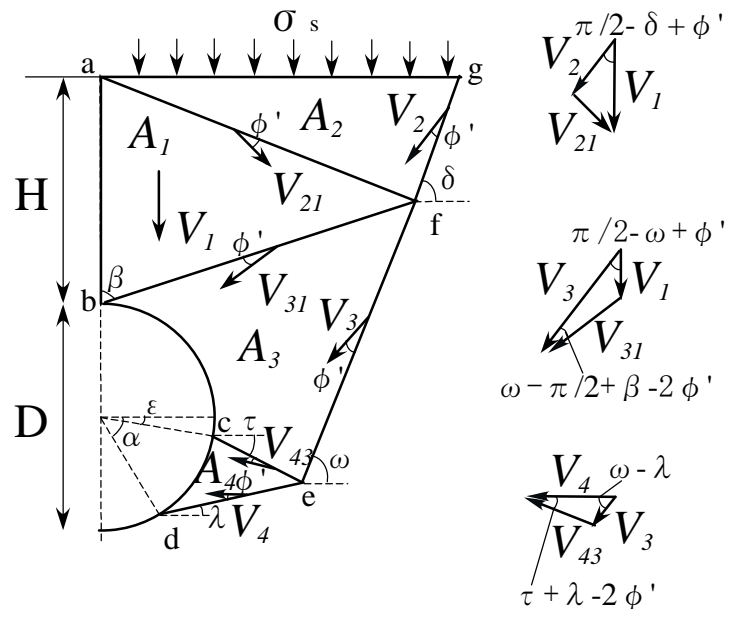


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Fig. 3. Upper-bound rigid-block mechanisms for a circular tunnel.

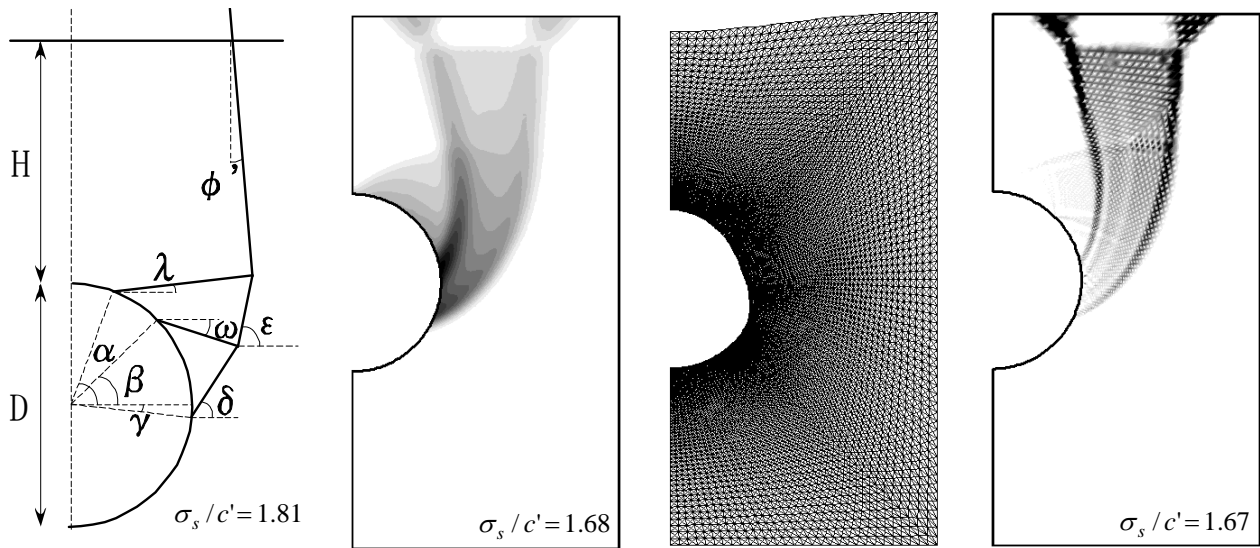


(e) Mechanism 5

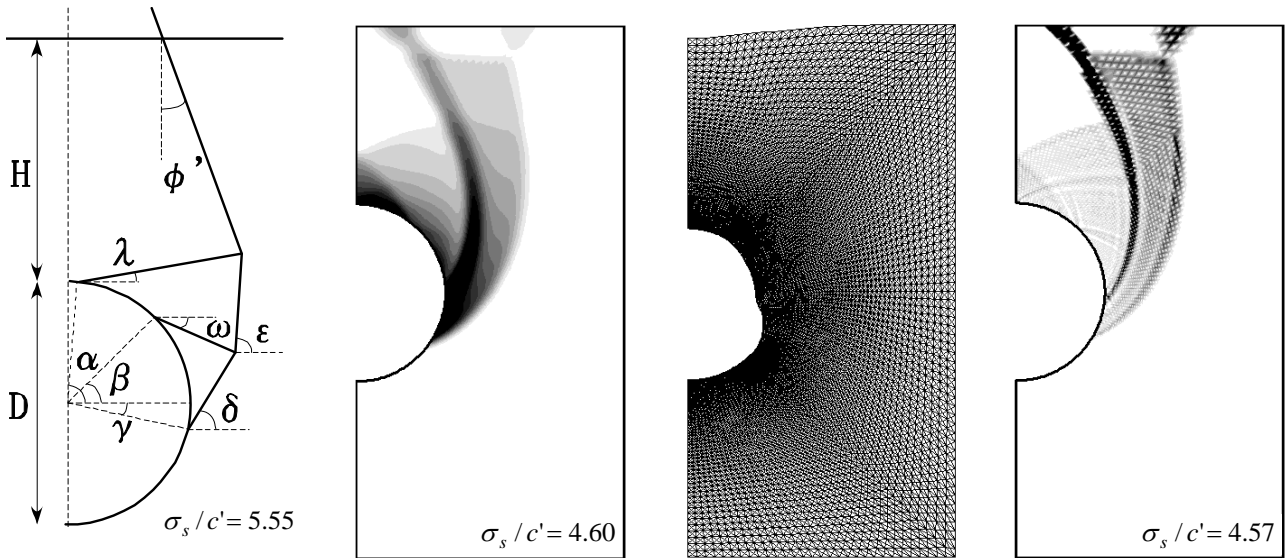


(f) Mechanism 6

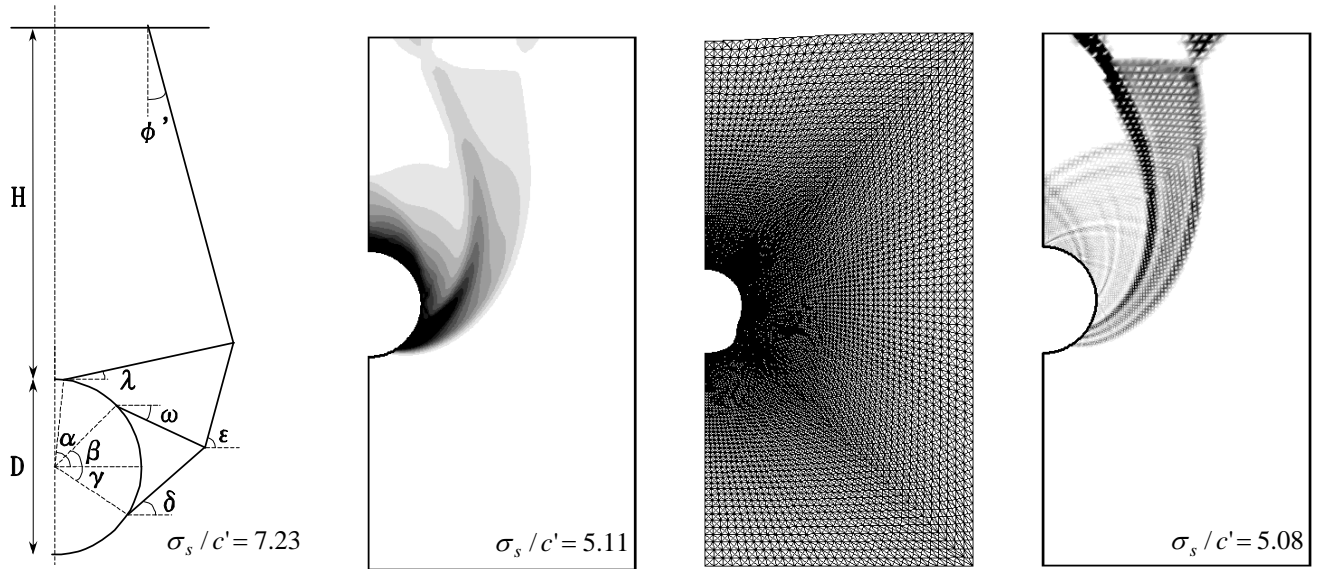
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(a) Rigid-block mechanism (b) Power dissipation (c) Deformed mesh (d) Plastic multiplier field
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 ($H/D=1, \phi'=5^\circ, \gamma D/c'=1$, smooth interface).



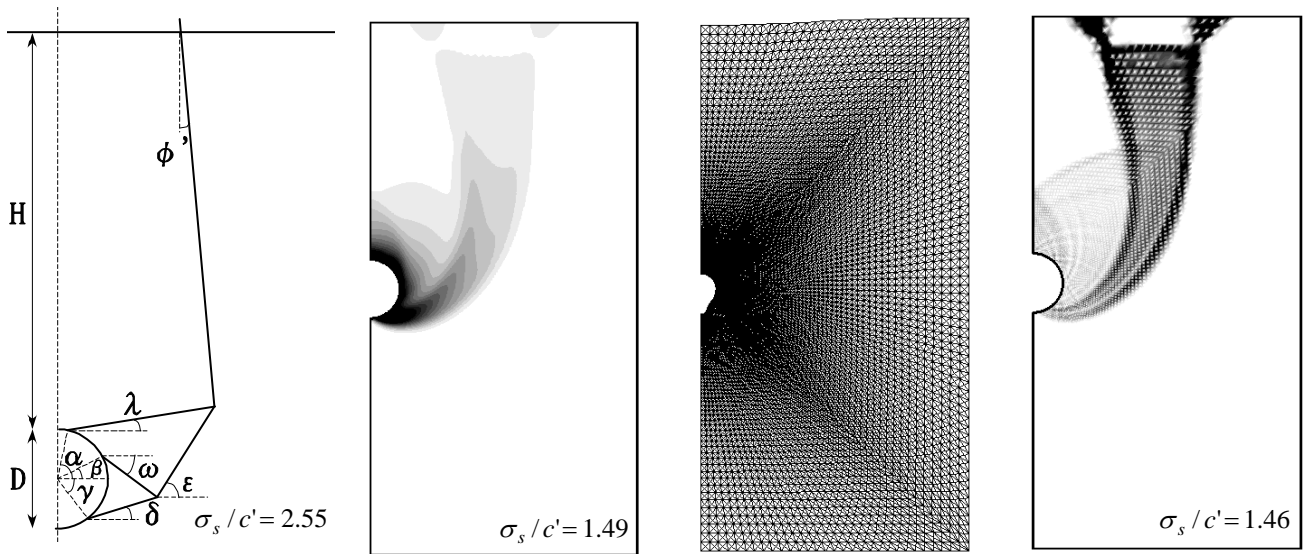
(a) Rigid-block mechanism (b) Power dissipation (c) Deformed mesh (d) Plastic multiplier field
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(a) Rigid-block mechanism (b) Power dissipation (c) Deformed mesh (d) Plastic multiplier field

Fig. 6. Comparison of rigid-block mechanism with finite element limit analysis

($H/D=2$, $\phi'=15^\circ$, $\gamma D/c'=1$, smooth interface).



(a) Rigid-block mechanism (b) Power dissipation (c) Deformed mesh (d) Plastic multiplier field

Fig. 7. Comparison of rigid-block mechanism with finite element limit analysis

($H/D=4, \phi'=5^\circ, \gamma D/c'=1$, smooth interface).

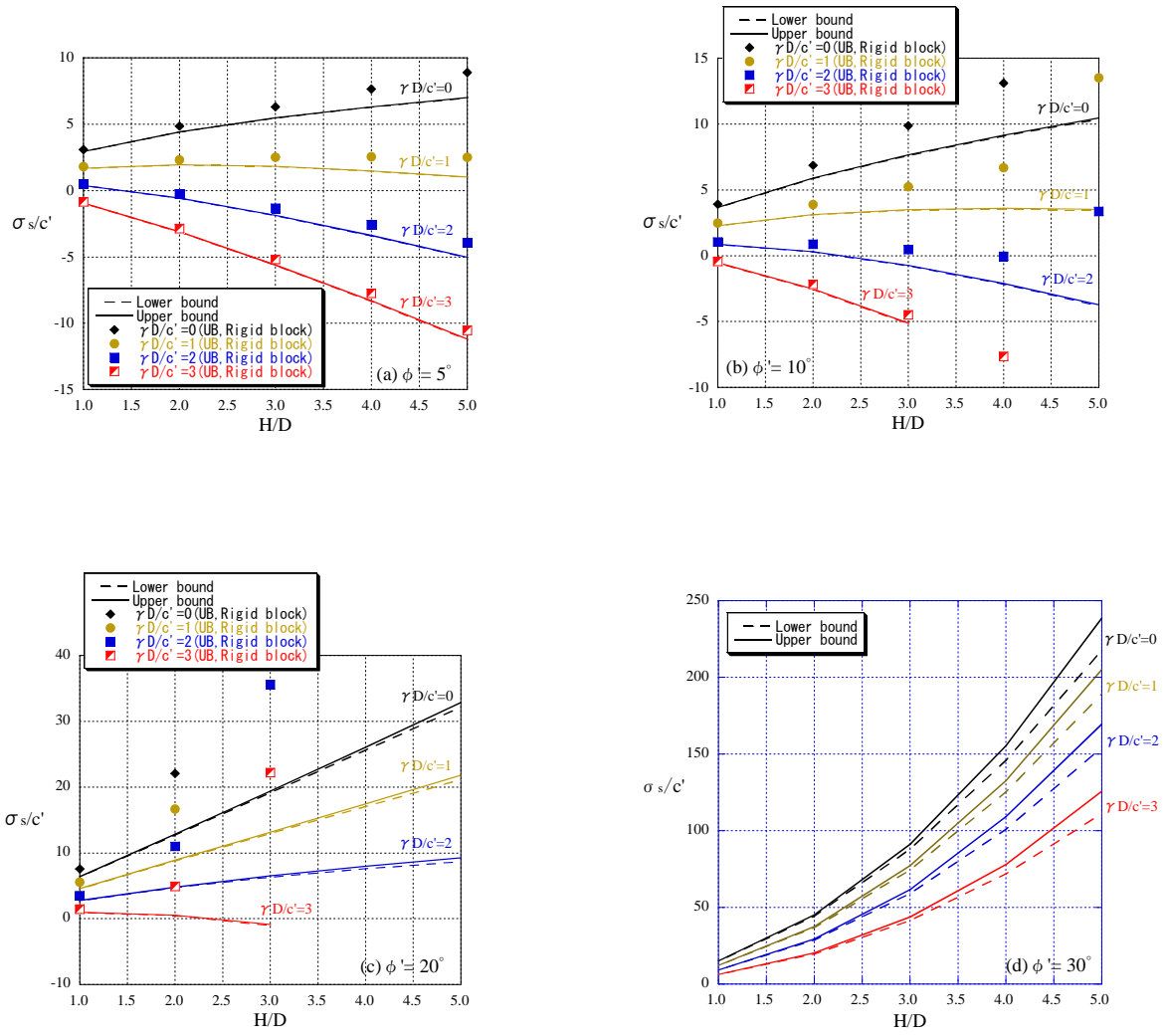


Fig. 8. Stability bounds for a circular tunnel ($\phi'=5^\circ, 10^\circ, 20^\circ$, and 30° , smooth interface).

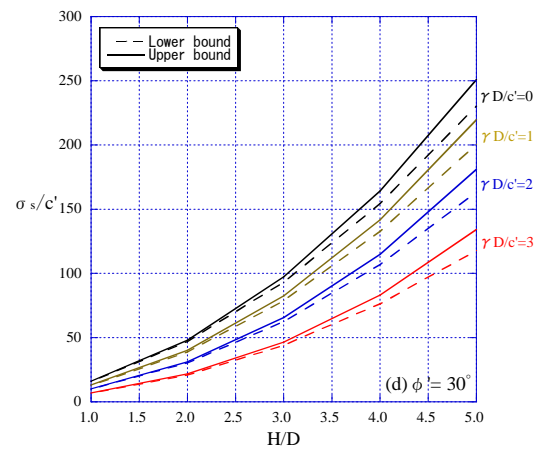
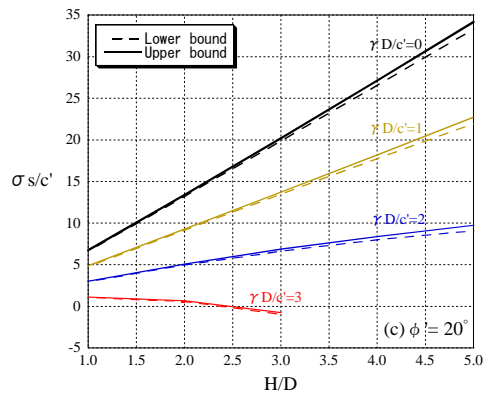
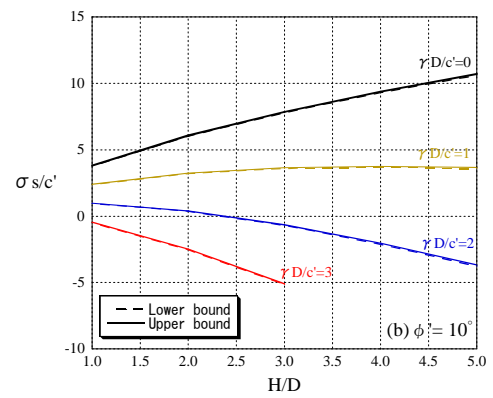
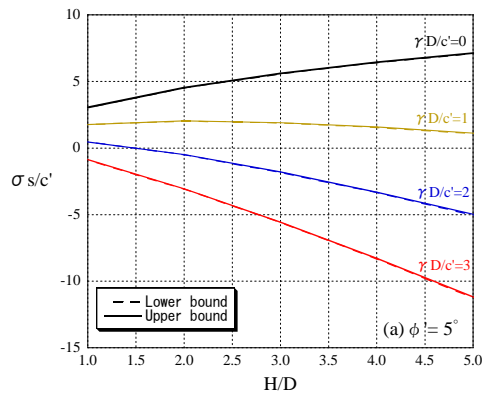


Fig. 9. Stability bounds for a circular tunnel ($\phi' = 5^\circ, 10^\circ, 20^\circ,$ and 30° , rough interface).