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General variational solution for seismic and static active earth pressure on rigid walls considering soil tensile strength cut-off

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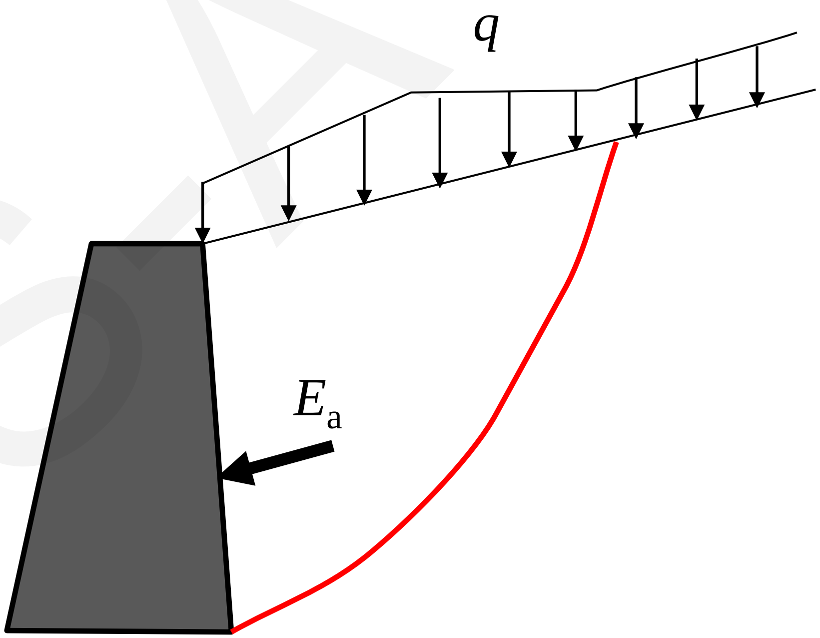
Defects of existing earth pressure methods

- Hypothesizing the shape of potential slip surface in the retained soil
- Failing to physically explain the relationship between the application point of the active resultant force and possible movement modes of the walls
- Being doubtful on the soil tensile strength involved in active earth pressure



General variational method for earth pressure

- **Static equilibrium conditions**

$$\overline{H} = \int_{l_{\mathrm{OM}}} (\tau\cos\eta - \sigma\sin\eta)\mathrm{d}l - k_h\left[\int_0^{x_{\mathrm{M}}} \gamma(s-y)\mathrm{d}x + F_{\mathrm{q}} + iG_{\mathrm{n}}\right] + E_{\mathrm{a}}\sin(\alpha-\delta) = 0,$$

$$\overline{V} = \int_{l_{\mathrm{OM}}} (\tau\sin\eta + \sigma\cos\eta)\mathrm{d}l - (1+k_v)\left[\int_0^{x_{\mathrm{M}}} \gamma(s-y)\mathrm{d}x + F_{\mathrm{q}} + iG_{\mathrm{n}}\right] + E_{\mathrm{a}}\cos(\alpha-\delta) = 0,$$

$$\overline{M} = \int_{l_{\mathrm{OM}}} [(\tau\sin\eta + \sigma\cos\eta)x - (\tau\cos\eta - \sigma\sin\eta)y]\mathrm{d}l - (1+k_v)\left[\int_0^{x_{\mathrm{M}}} \gamma(s-y)x\mathrm{d}x + M_{\mathrm{qv}} - iM_{\mathrm{nv}}\right]$$
$$+ k_h\left[iM_{\mathrm{nh}} + \int_0^{x_{\mathrm{M}}} \frac{\gamma}{2}(s^2-y^2)\mathrm{d}x + M_{\mathrm{qh}}\right] - E_{\mathrm{a}}\left[\sin(\alpha-\delta)z_{\mathrm{a}} + \cos(\alpha-\delta)\frac{z_{\mathrm{a}}}{\tan\alpha}\right] = 0.$$

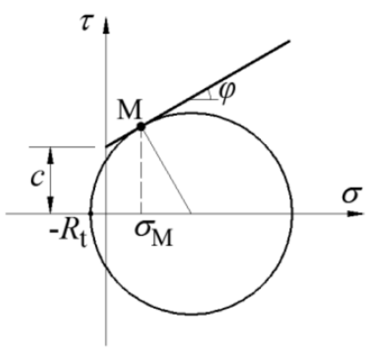
⇩

- **Basic function**

$$\int_0^{x_{\mathrm{M}}} (\overline{V} + \lambda_1\overline{H} + \lambda_2\overline{M})\mathrm{d}x = 0$$

⇧

- **Tensile strength cut-off**



$$R_{\mathrm{t}} = \psi\frac{2c\cos\phi}{1+\sin\phi}.$$

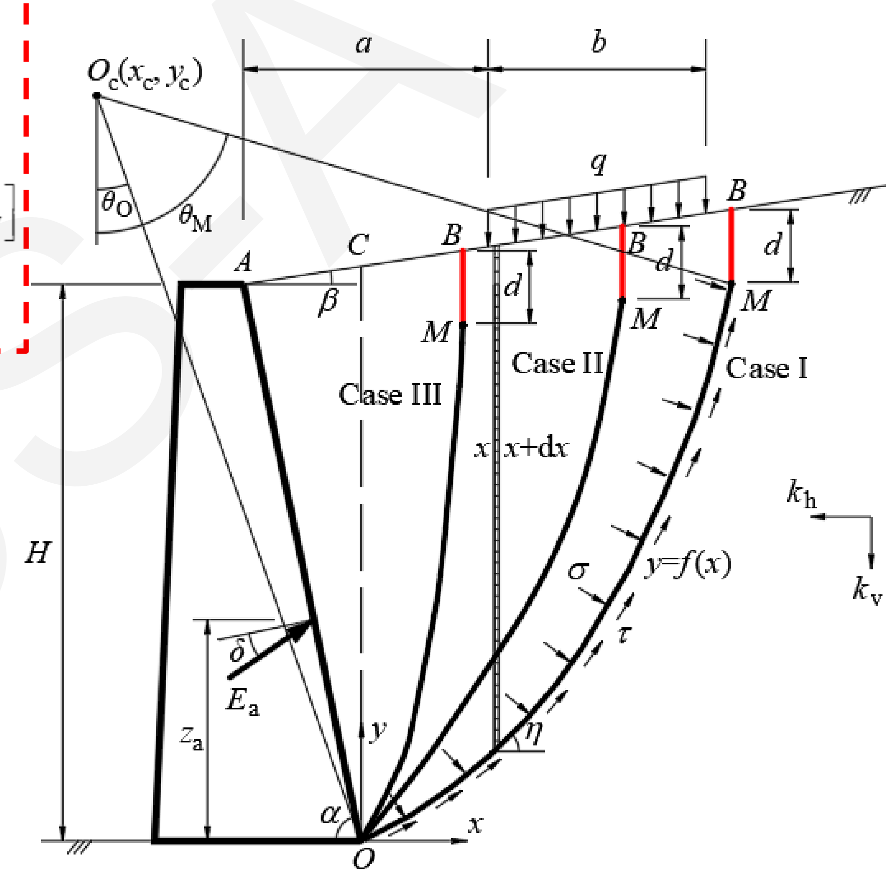


Fig. 1 General analysis model

ψ is a non-negative calibration coefficient no greater than 0.5 at point M.

Relationship between application point and wall movement modes

According to some test results (Niedostatkiewicz et al., 2011), it can be inferred that there is three basic relationship between the application point of the active resultant force and possible movement modes of the walls.

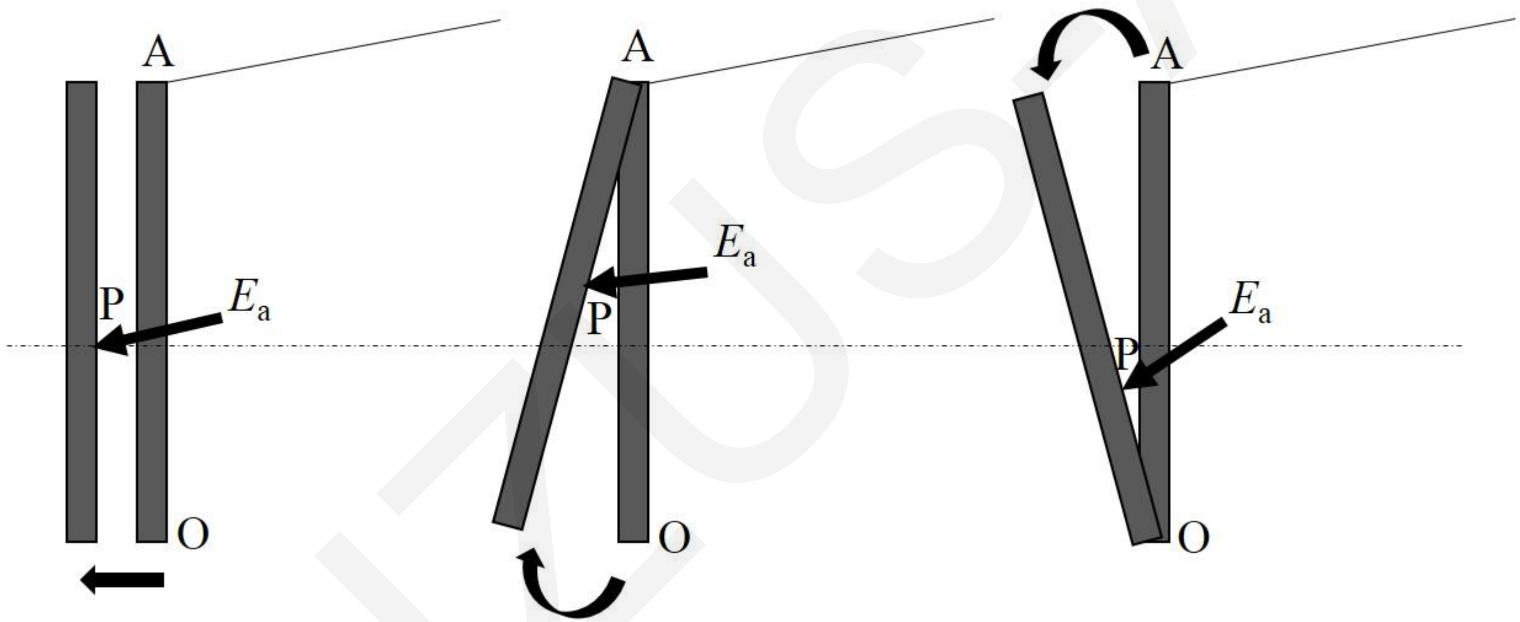
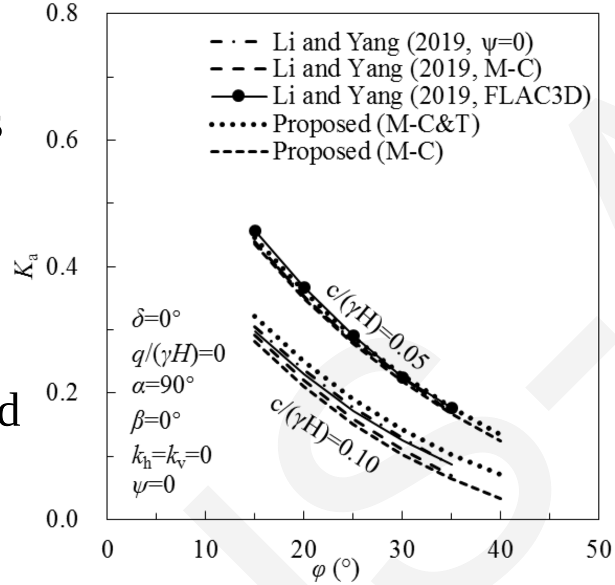


Fig. 2 Relative locations of application point of the active resultant force in three cases

In fact, the location of the application point of the active thrust is closely related to the movement modes of the wall which are influenced by some practical circumstances such as foundation conditions and restraints in front of the wall.

Verification

The critical slide mass by the proposed method (M-C & T) is relatively close to that by the limit analysis method (Li and Yang, 2019), but the shape and depth of the tension crack are much more adequately reflected by the proposed method (M-C & T) than the limit analysis method.



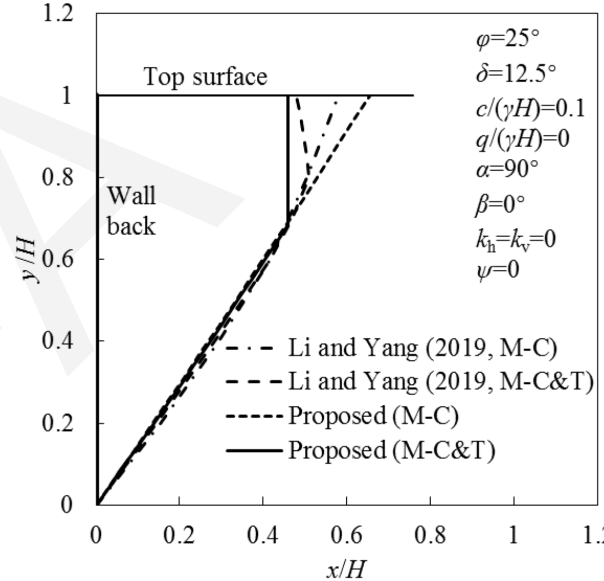
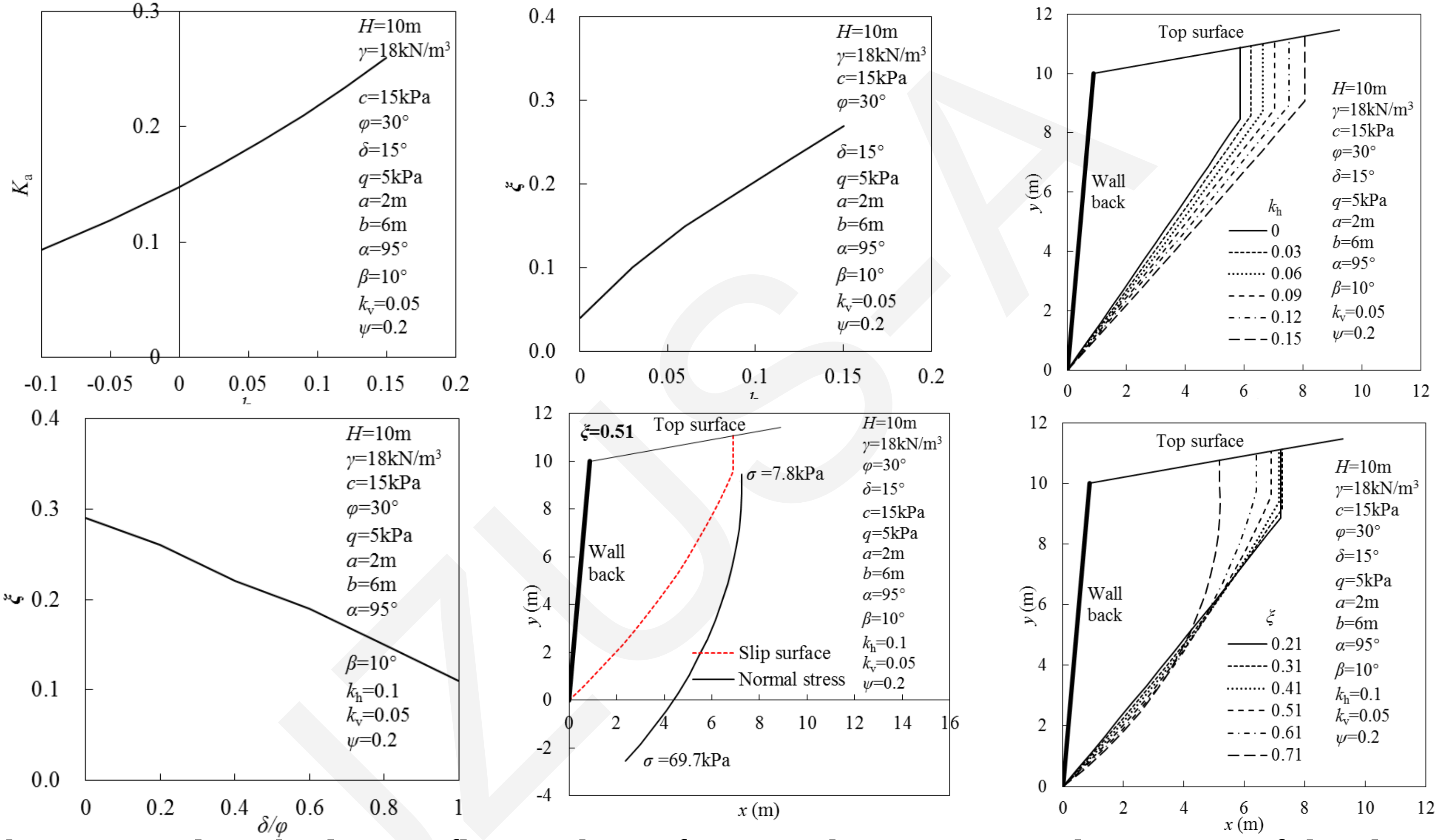


Table 1 Active earth thrust under strip surcharge (γ=20kN/m^3, c=10kPa, ϕ=30°, δ=10°, ψ=0, H=10m, α=90°, and β=0°; unit: kN/m)

q (kPa)	a (m)	b (m)	Beton Kalender (1983)	45° distribution (Cernica, 1995)	45° +φ/2 distribution (China Code GB50330-2013, 2014)	Farzaneh et al. (2014)	Proposed (ξ)
10	2	1	241.3	231.2	233.6	210.7	215.6 (0.25)
20	2	1	254.8	234.5	239.4	216.7	220.7 (0.26)
30	2	1	268.3	237.9	245.2	222.8	225.6 (0.26)
20	4	1	270.2	234.5	239.4	216.7	220.7 (0.24)
50	4	1	333.7	244.5	256.7	235.3	235.5 (0.23)
100	4	1	439.6	261.2	285.6	267.1	259.1 (0.21)
20	3	2	274.1	241.2	251.0	228.3	230.6 (0.24)
20	3	3	285.6	247.9	262.5	235.6	233.1 (0.23)
20	3	4	297.1	254.5	274.1	235.8	233.1 (0.23)
10	0	2	233.6	228.8	233.6	216.4	220.7 (0.27)
10	0	3	239.4	232.1	239.4	221.8	225.7 (0.28)
10	0	4	245.2	235.4	245.2	227.0	230.5 (0.27)

The existing approaches are averagely more conservative than the proposed method.

Parameter study



- The proposed method can reflect 13 basic factors. The tension crack segment of the slip surface is obviously influenced by most of these parameters, but the shear slip segment maintains an approximately planar shape almost uninfluenced by these parameters.
- The proposed method quantitatively presents that the resultant is always within a limited range under different possible movements of the same wall.

Conclusions

- Variational solution for seismic active earth pressure on walls considering soil shear and tension failure is put forward.
- Variation range of the active earth pressure on a practical rigid wall under possible composite movements can be obtained.
- Effects of 13 basic factors on the earth pressure and corresponding shear-tension composite slip surface are exhibited.
- Tension crack is related to these factors except vertical seismic coefficient and geometric bounds of strip surcharge.
- Shear segment of the slip surface is varying from planar to curved mode as the application point of the resultant rises.
- Calibration coefficient of soil tensile strength has slight effect on normal stress on the critical shear segment.

Published other papers by the authors

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