The Preliminary Study of the Impact of Liquefaction on Water Pipes

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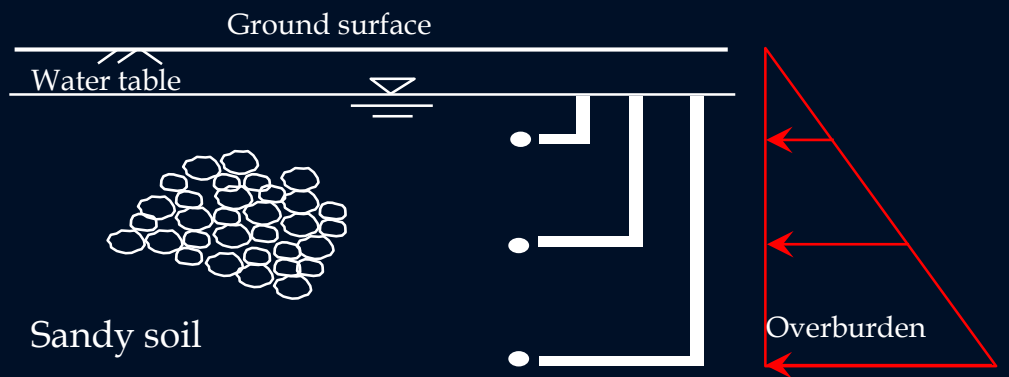
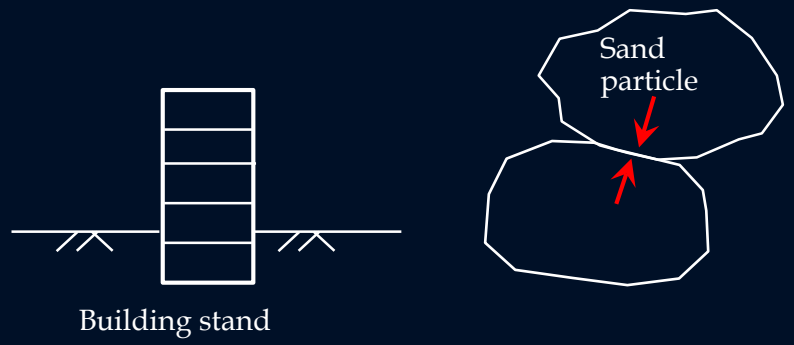
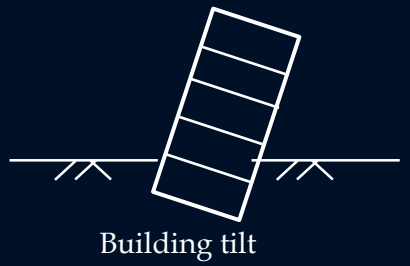
Introduction

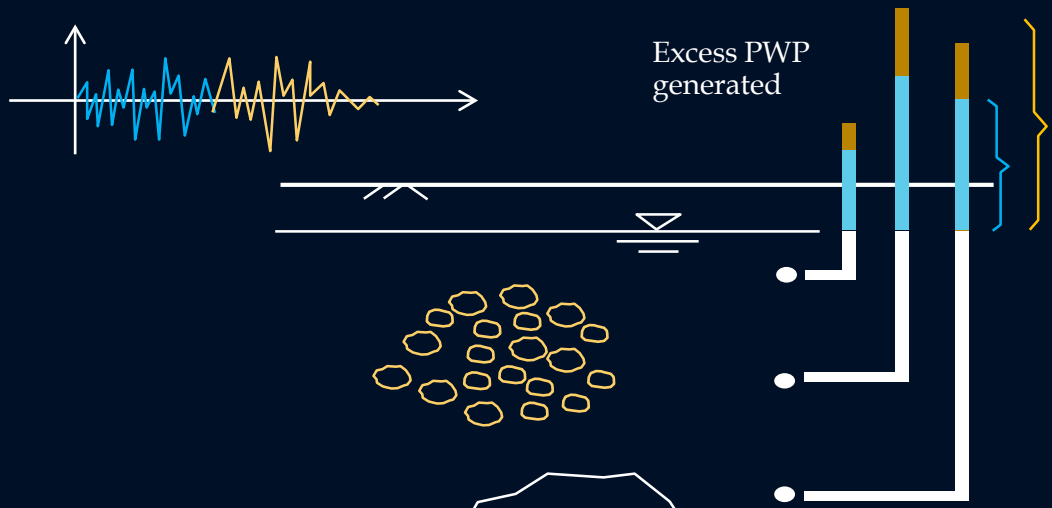
- Damages to the existing tap-water pipes have been found after earthquake.
- Some of these damages are derived from the soil liquefaction.
- Dissipation of pore pressure after soil liquefaction will cause ground subsidence.
- Loose sand can easier generate pore water pressure and cause a larger settlement.
- The greater liquefaction thickness, the larger ground settlement and a more severe damage to DIP
- Damage of DIP occurs mainly at the border between soil with /without liquefaction.
- Elongation and bending are the most common damage type happened in earthquake.
- Installation of flexible joints aims to reduce the damage to the tap-water pipes.

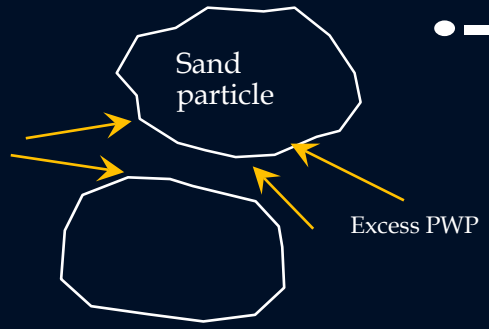
Behaviour of liquefaction

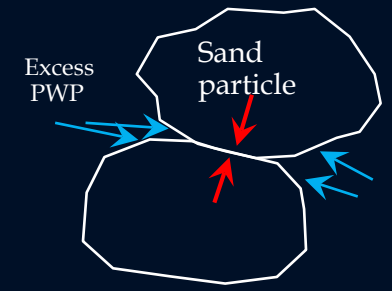








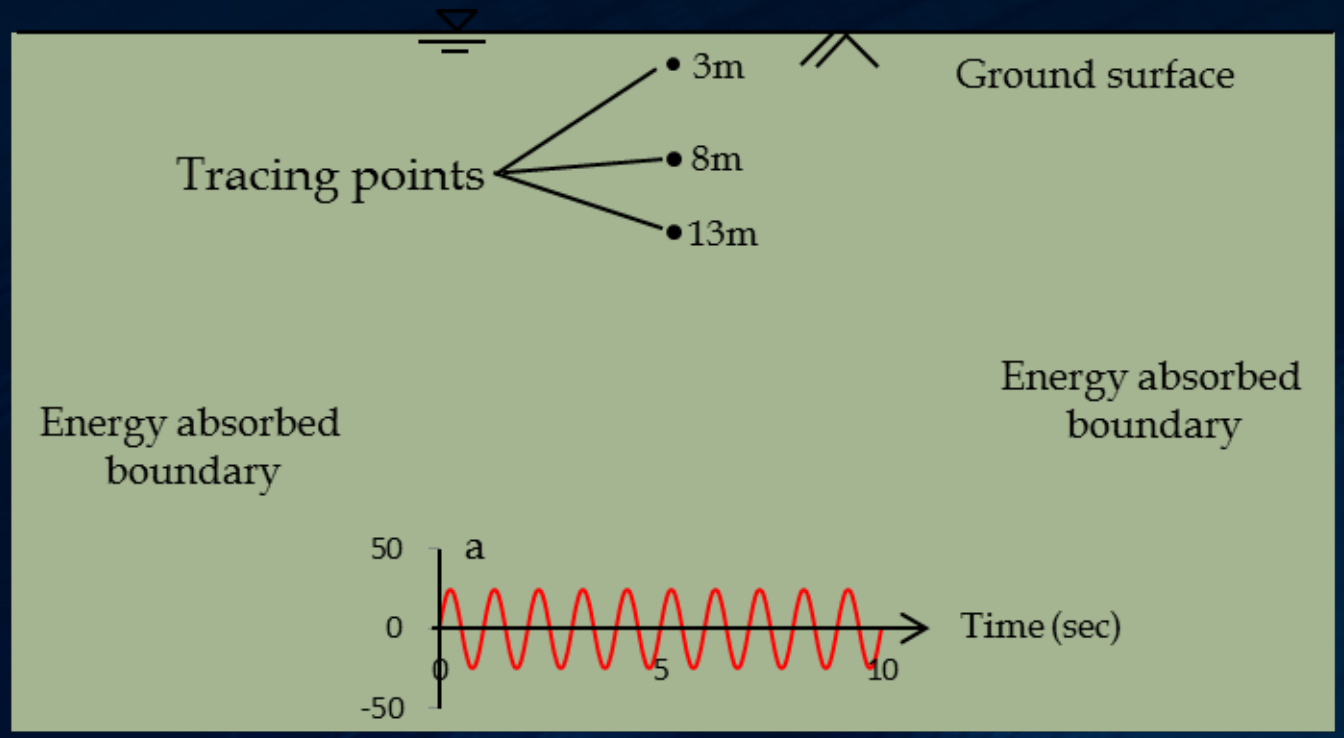


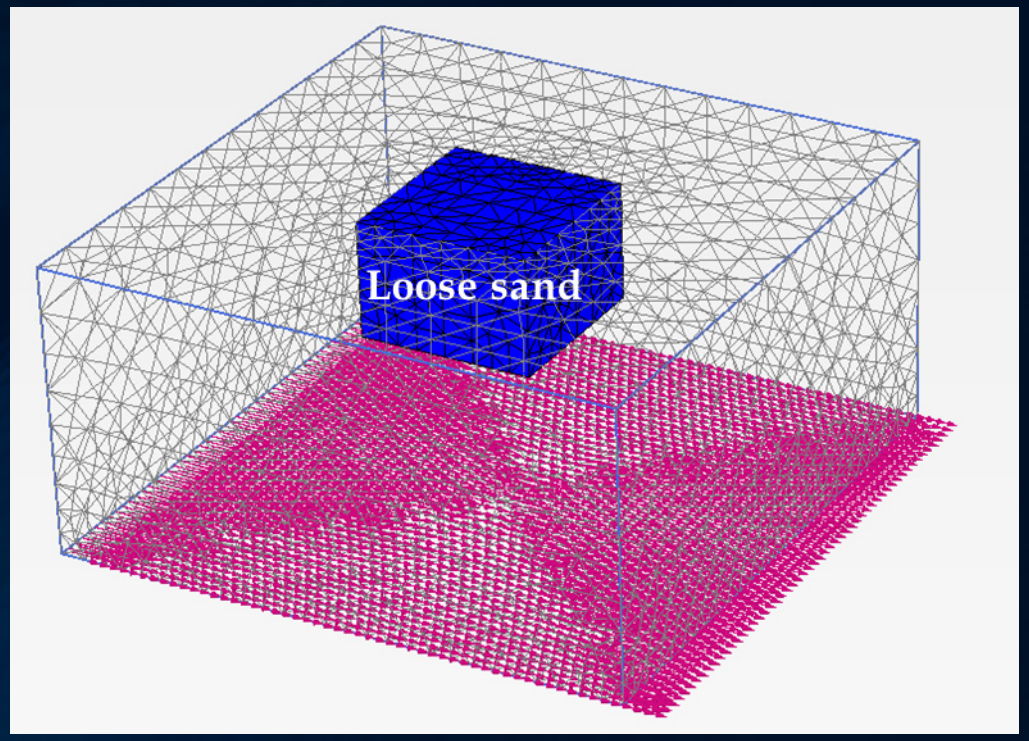


Jerry

Layout of numerical calculation

- In PLAXIS it is possible to simulate pore pressure generation derived from SH wave excited at ground bottom, as shown in Figure.
- The finite element mesh in calculation is shown in Figure.





Excess pore pressure generation

- **PLAXIS has options to deal with undrained behaviour in an effective stress analysis**
- **Water is supposed not to sustain any shear stress, Accordingly, the excess pore water pressure is related to isotropic stress**

$$\Delta\sigma = \frac{1}{3}(\Delta\sigma_1 + \Delta\sigma_2 + \Delta\sigma_3)$$

Excess pore water pressure $\sigma_{excess} = \mathrm{B}\sigma = \frac{\alpha\varepsilon_v}{nC_w+(\alpha-n)C_s}$

$\mathrm{C_w} = 1/\mathrm{K_w}$ $\mathrm{C_s} = 1/\mathrm{K_s}$

Effective $\sigma' = (1 - \alpha\mathrm{B})\sigma = \mathrm{K}'\varepsilon_v$

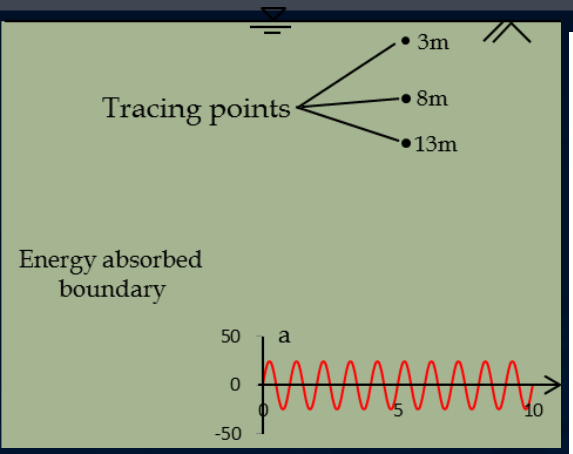
$\mathrm{K_W}$ is the bulk modulus of water;

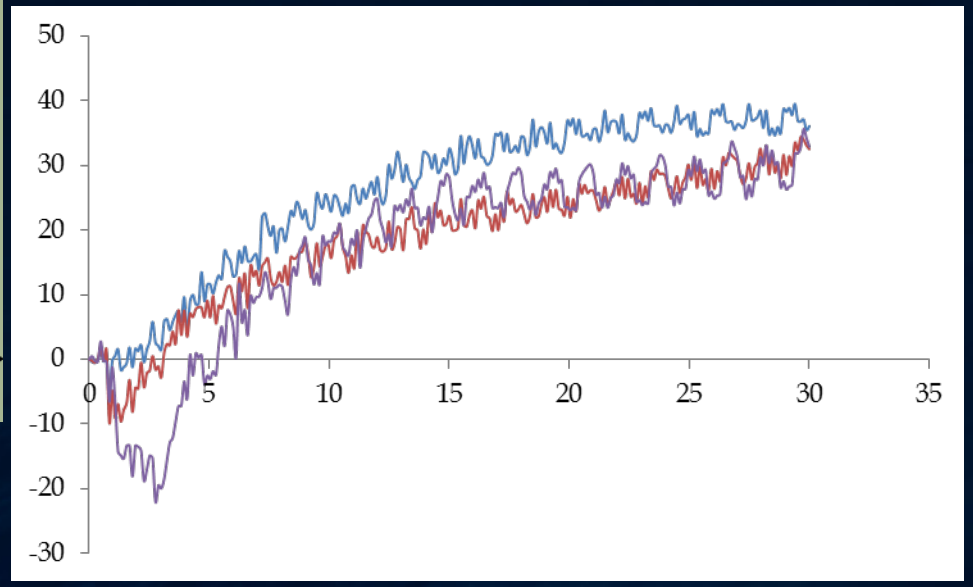
$\mathrm{K_S}$ is the bulk modulus of soil material;

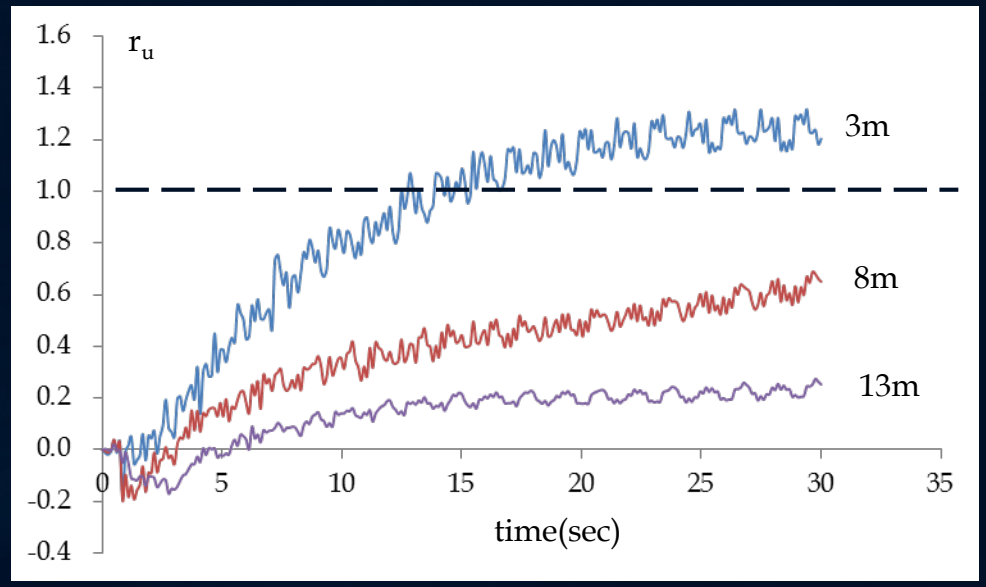
n is the soil porosity;

B is the Skempton parameter.

Excess pore pressure generation and liquefaction







Pore pressure ratio (r_u)

5m

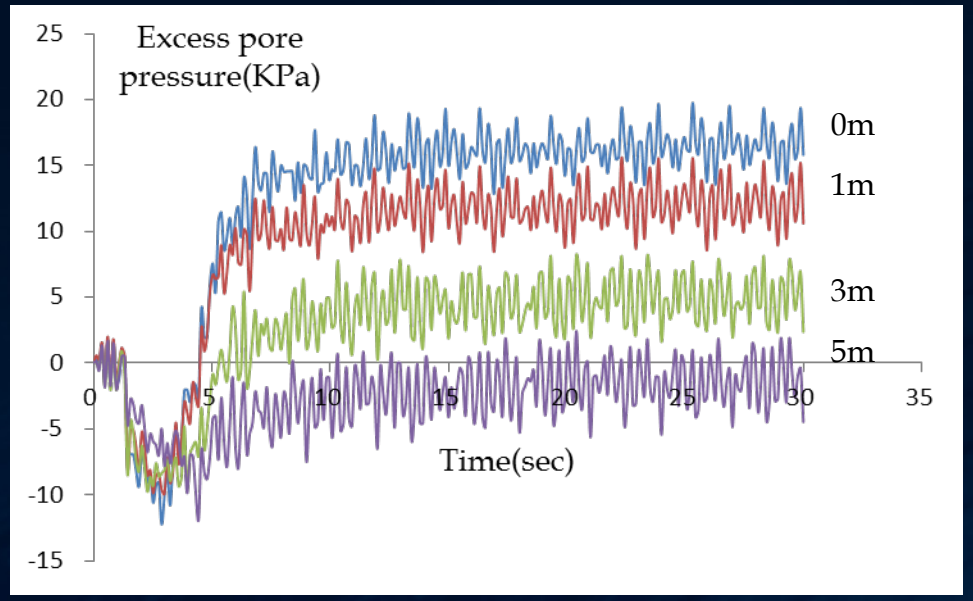
13m

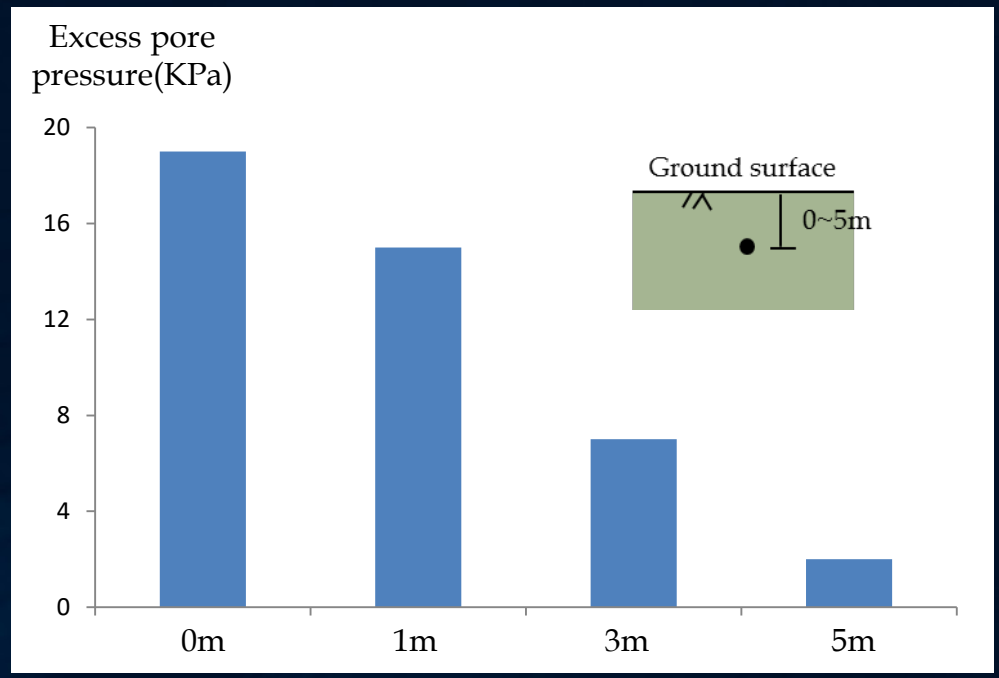
time(sec)

$$\text{Excess pore pressure ratio } r_u = \frac{\text{excess pore water pressure } (u_w)}{\text{effective overburden pressure}(\sigma'_v)}$$

- **Excess pore pressure seems not much difference.**
- **But, excess pore pressure stress ratio r_u is obviously difference**
- **r_u=1.0, if liquefaction happened**

Excess pore water generated in various water tables

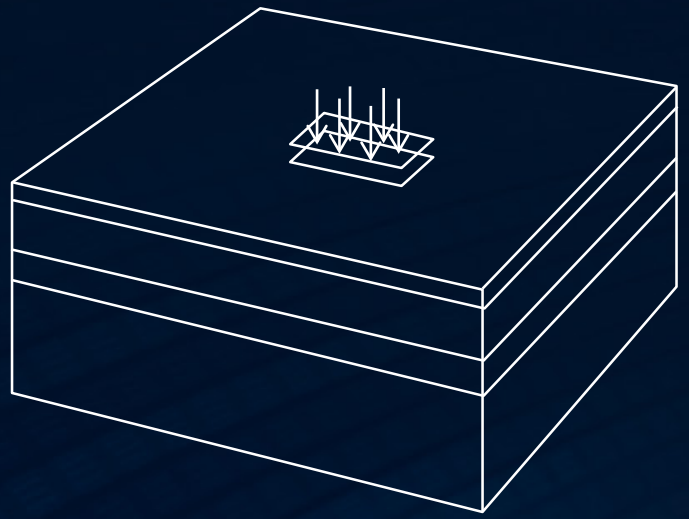




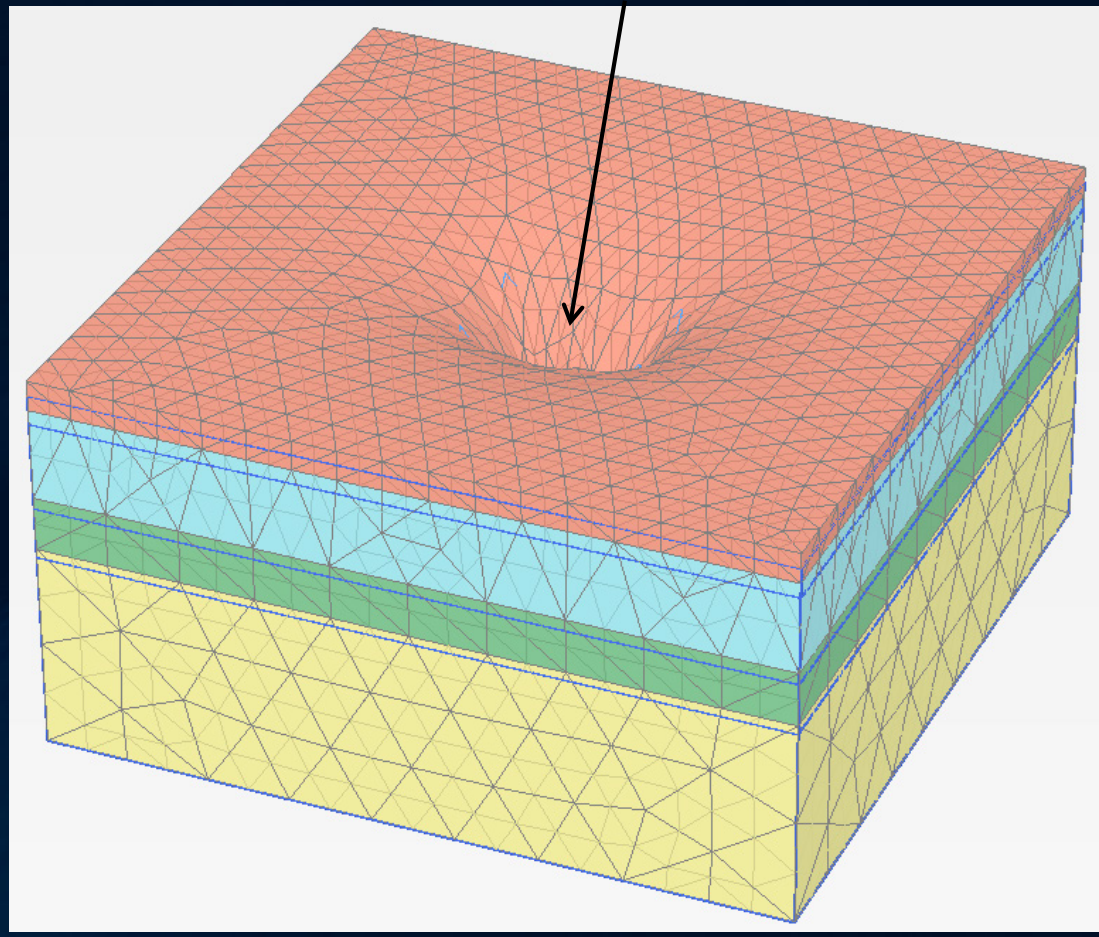
- **The location of ground water table will dramatically affect the liquefaction potential**
- **It is difficult to bring about liquefaction if the underground water located at more than 5m below the ground surface.**

Pore pressure dissipation and settlement

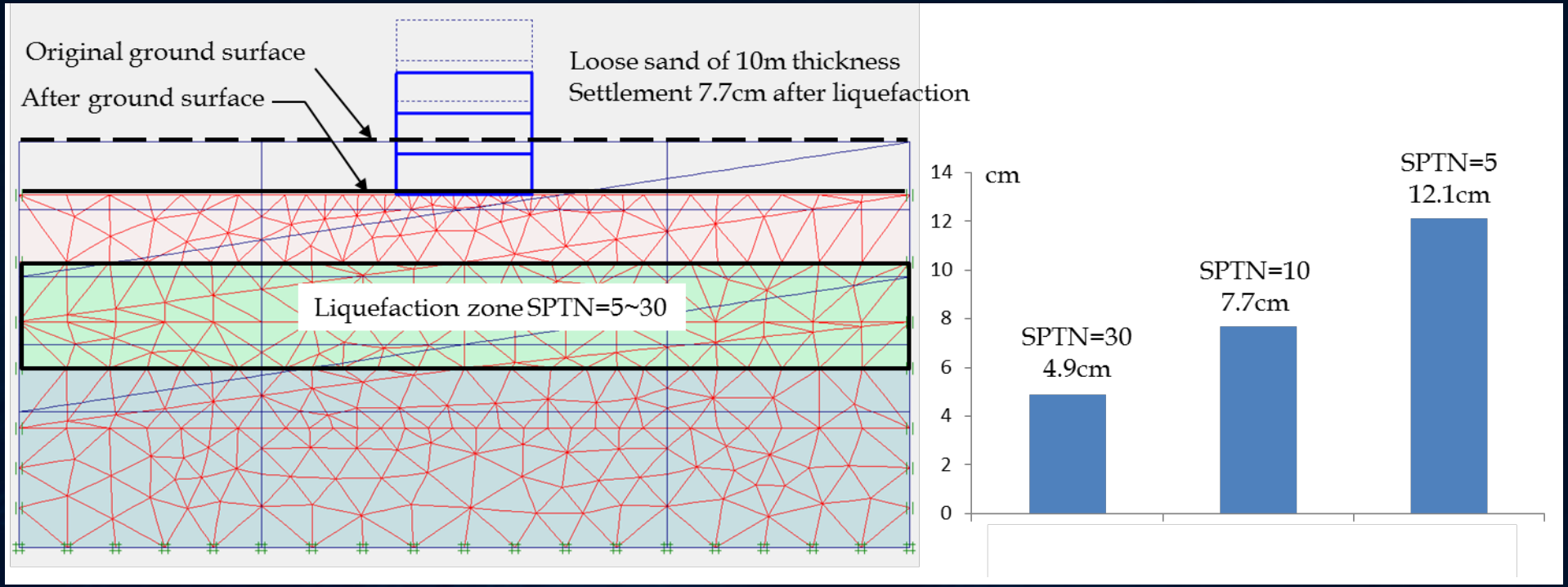
- Liquefaction means the excess pore pressure derived from earthquake equals to the effective overburden weight.
- The dissipation of excess pore water pressure is equivalent to the effective overburden weight re-compress the ground , which will lead to the ground settlement.



ground settlement due to liquefaction

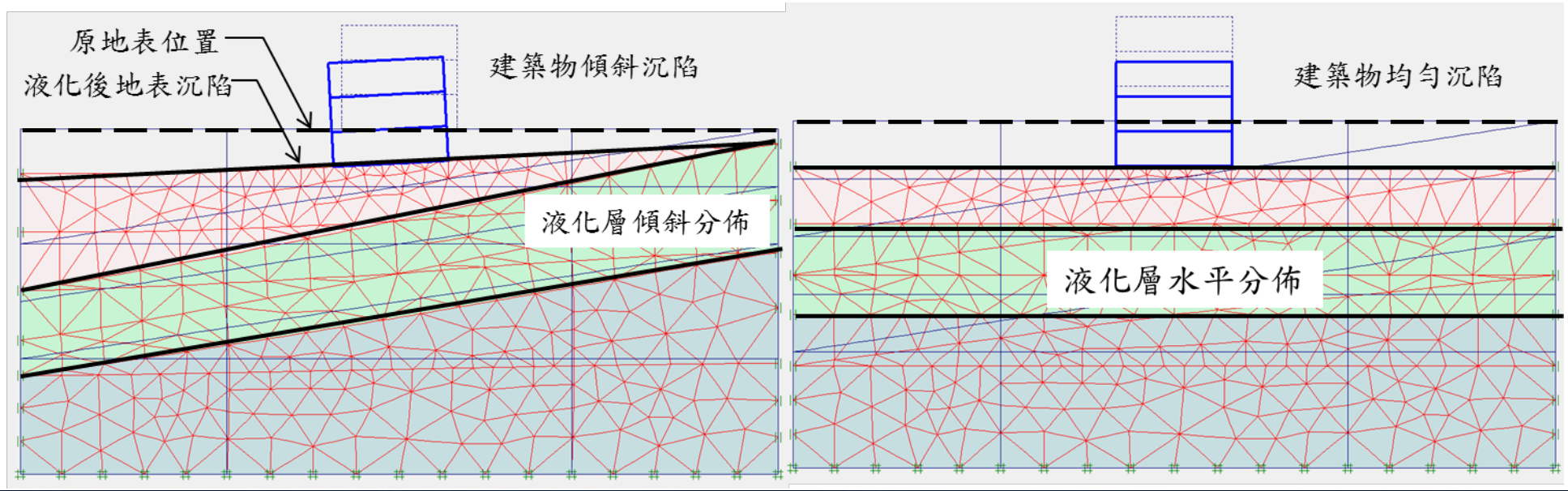


Ground settlement due to various sand properties



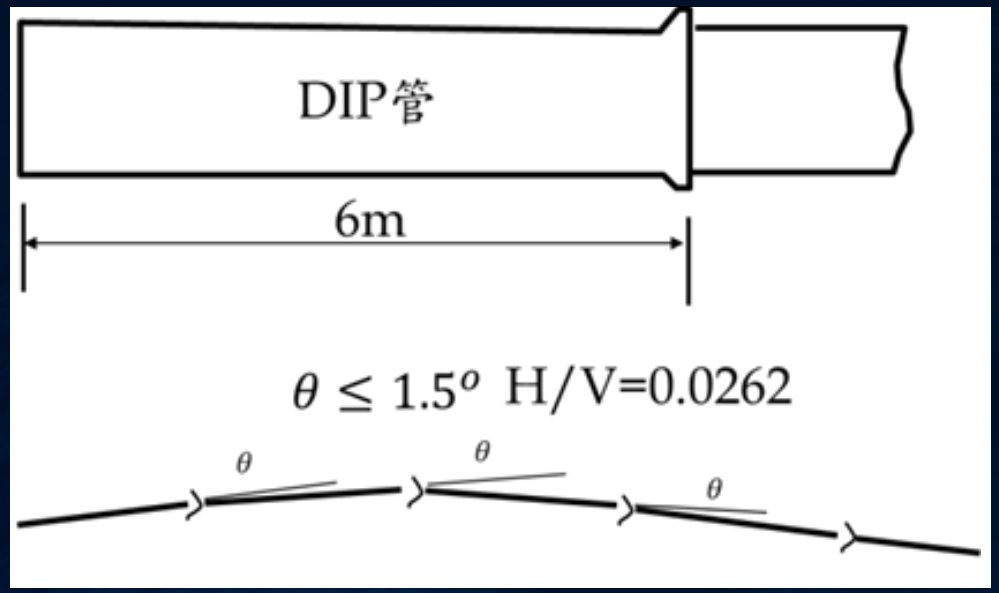
- The loose sand can easier generate pore water pressure and cause a larger settlement.
- A greater liquefaction thickness will cause a larger ground settlement.

Ground settlement due to distribution of liquefaction



- The distribution of liquefaction zone will affect the distribution of ground settlement.
- The incline liquefaction zone will lead to the building tile after earthquake if liquefaction happened, as shown in Figure.

Allowable rotation angle of ductile cast-iron pipe



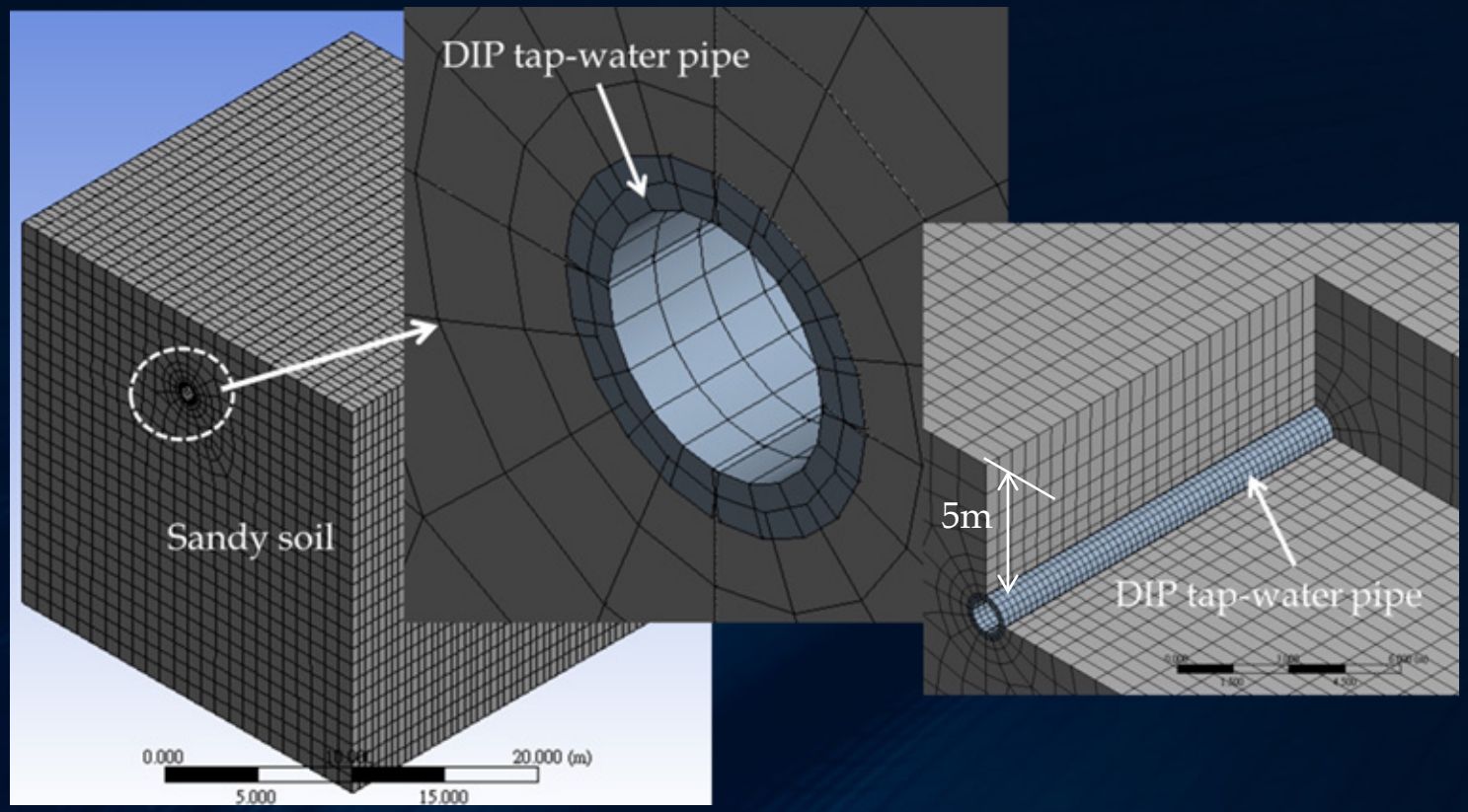
The allowable amount of expansion/compression and rotation angle is 3.4cm and 1.5°, respectively, which corresponds to the rate of change in the vertical and horizontal is 0.0262, H/V=0.0262.

The engineering properties of ground and DIP

Engineering properties adopted in numerical analysis

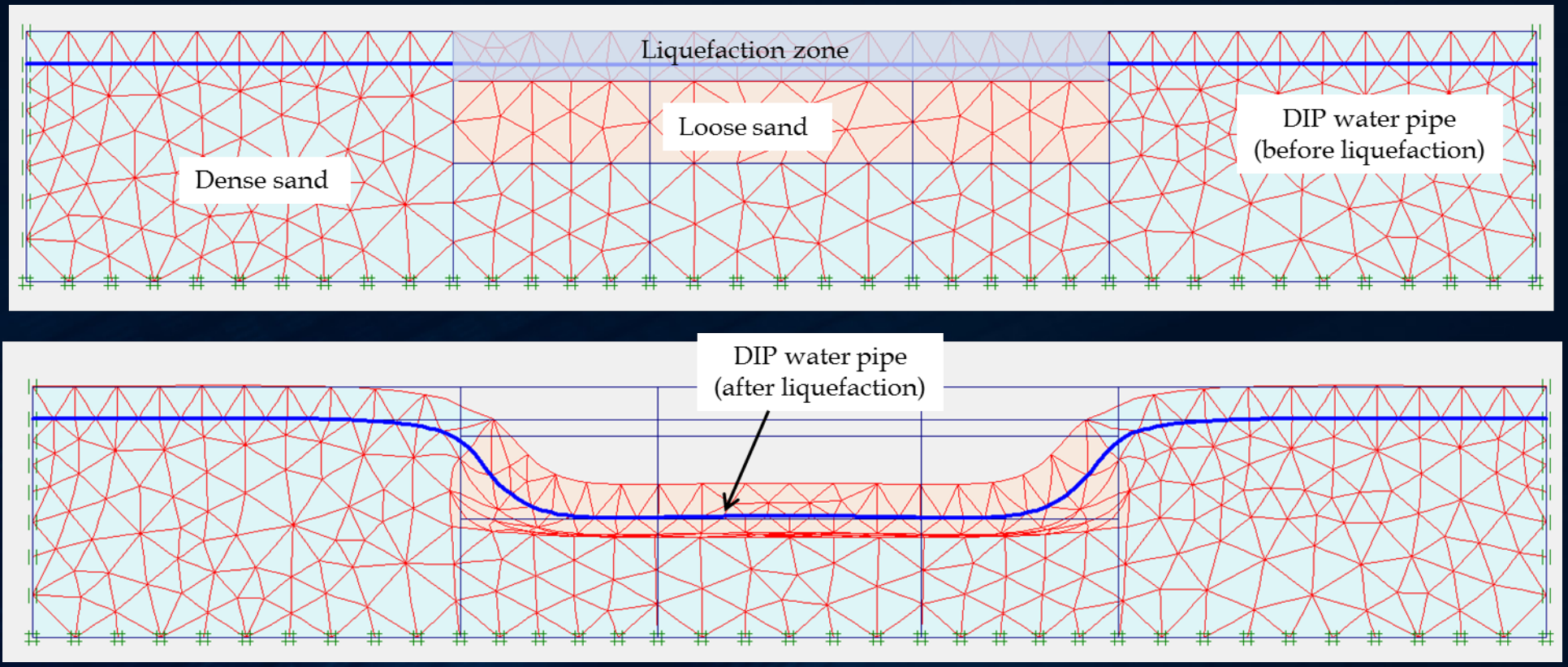
	SPT-N	E (KPa)	υ	c (KPa)	φ (degree)	Remark
Sand_1	5	10000	0.35	5	29	Loose sand
Sand_2	35	70000	0.32	5	38	Dense sand
DIP	-	1.67E8	0.33	-	-	

Finite element mesh in numerical calculation



- The configuration and finite element mesh in numerical calculation is shown in Figure
- To avoid the difficult selection of soil spring parameters in SSI, the soil and DIP tap-water pipe shall be simultaneously considered in the three-dimensional numerical calculations.

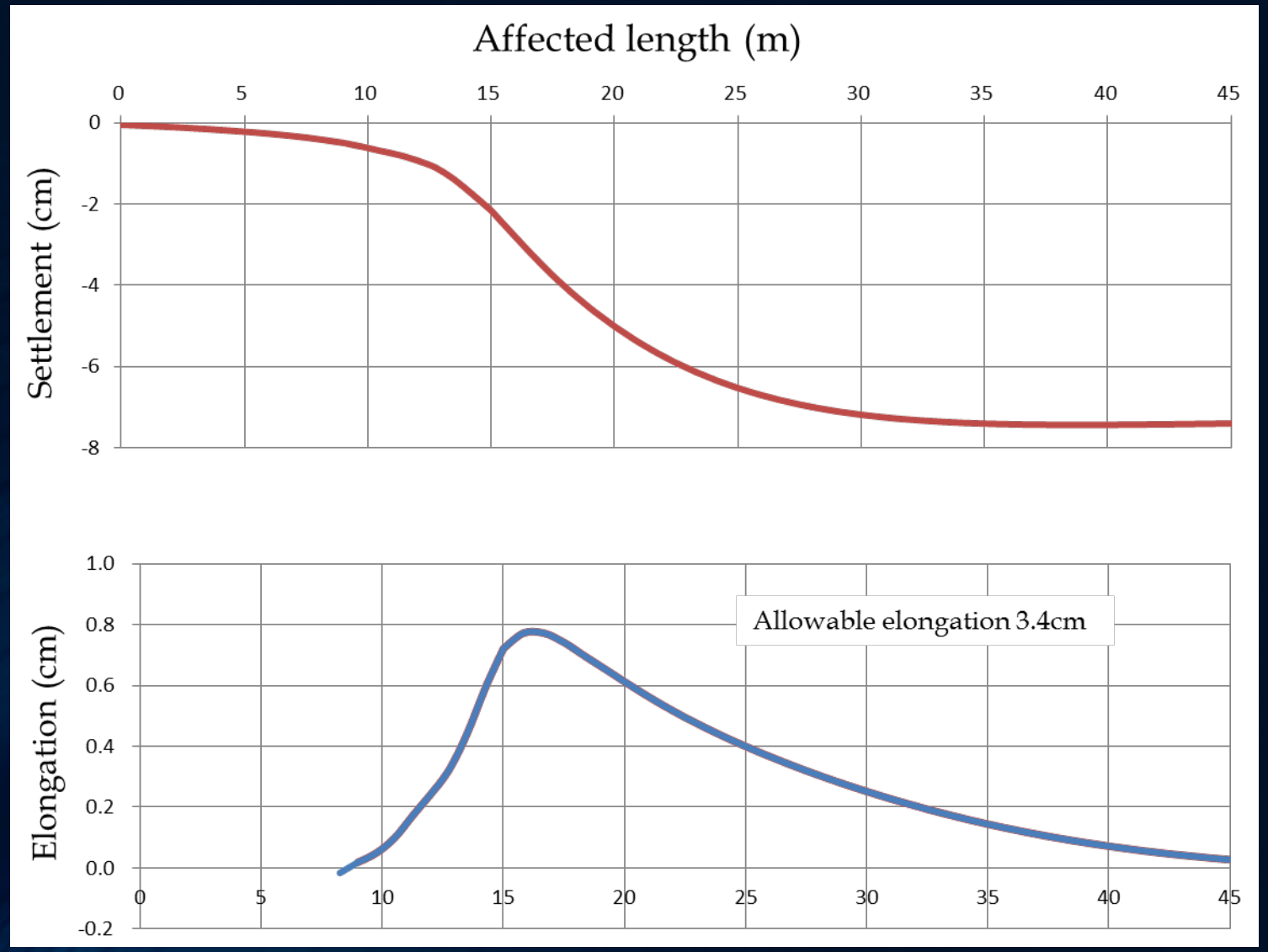
Ground settlement due to liquefaction



- The ground settlement and DIP's deformation due to liquefaction are given in Figure.
- The liquefaction settlement will affect a nearby range where the DIP tap-water pipe will be subjected to an extra elongation and will lead to an extra axial force and bending moment..

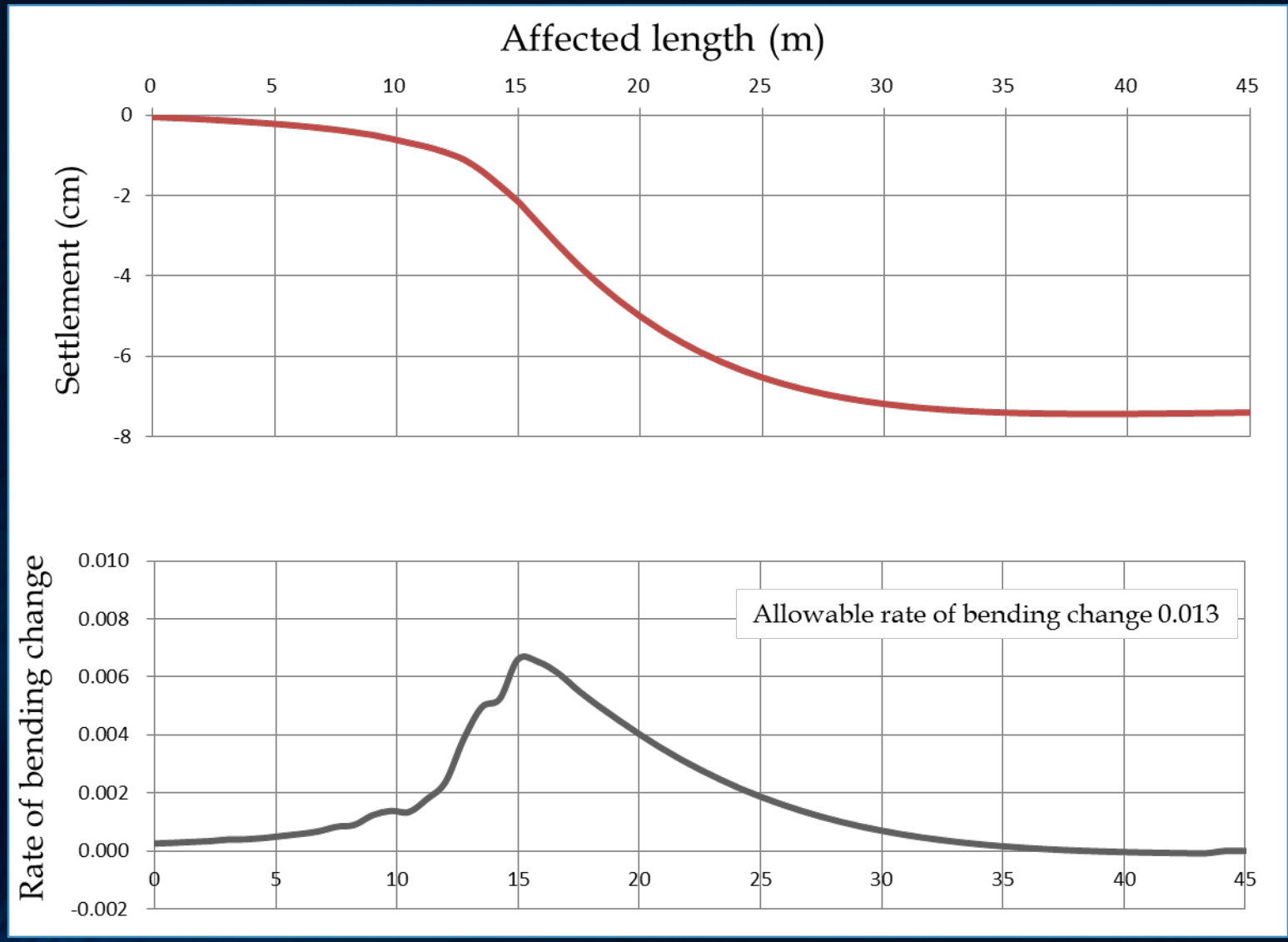
Elongation of DIP due to liquefaction

- The shape of the stretched pipe looks like a hyperbolic secant curve.
- The largest deformation and bending angle of the tap-water are all at in the middle of the stretched curve.
- The numerical calculation shows that the elongation of DIP tap-water pipe resulted in liquefaction settlement is only 0.8cm, which has no exceeding the allowable limit 1.7cm.



Bending of DIP due to liquefaction

- Rate change of elongation indicates the bending angle of DIP and it looks like a similar to Gauss curve.
- The rate is about 0.0075, which is much less the allowable limit of 0.013.
- The axial elongation and bending angle have to be examined to understand whether the liquefaction will cause the damage to the DIP tap-water pipe..



Installation of flexible joints

- Usually, a larger liquefaction thickness corresponds to a greater ground settlement and the DIP water-pipe will be subjected to a stretch displacement.
- To reduce the extra force on tap-water pipes, flexible joints are suggested to be installed to absorb the stretch displacement of water-pipe.
- The stretch displacement takes place at the border between soil with /without liquefaction and the shape of the stretch displacement likes an Gaussian curve.
- The most elongation of water-pipe is at the middle of the stretch range so that the function of the flexible joint can be fully developed if the flexible joint is installed in the middle of the stretching range.

Conclusions

- The location of ground water below the ground surface will dramatically affect the liquefaction potential of soil.
- The loose sand can easier generate pore water pressure and cause a larger settlement. Also, a greater liquefaction thickness will cause a larger ground settlement.
- To avoid the difficult selection of soil spring parameters in the calculation of soil-structure interaction, it has been suggested that soil and water-pipe shall be simultaneously considered in the three-dimensional numerical calculations.

Conclusions

- The larger ground settlement will result in a more severe damage to DIP tap-water pipes, in particular, when the DIP tap-water pipes are located at the boundary between liquefied and non-liquefied areas.
- Except for the bending of DIP, it also needs to examine the amount of DIP elongation. The flexible joint can absorb the DIP elongation and reduce the bending of DIP.
- The most elongation of water-pipe is at the middle of the stretch range so that the function of the flexible joint can be fully developed if the flexible joint is installed in the middle of the stretching range.

Thank you for your listening