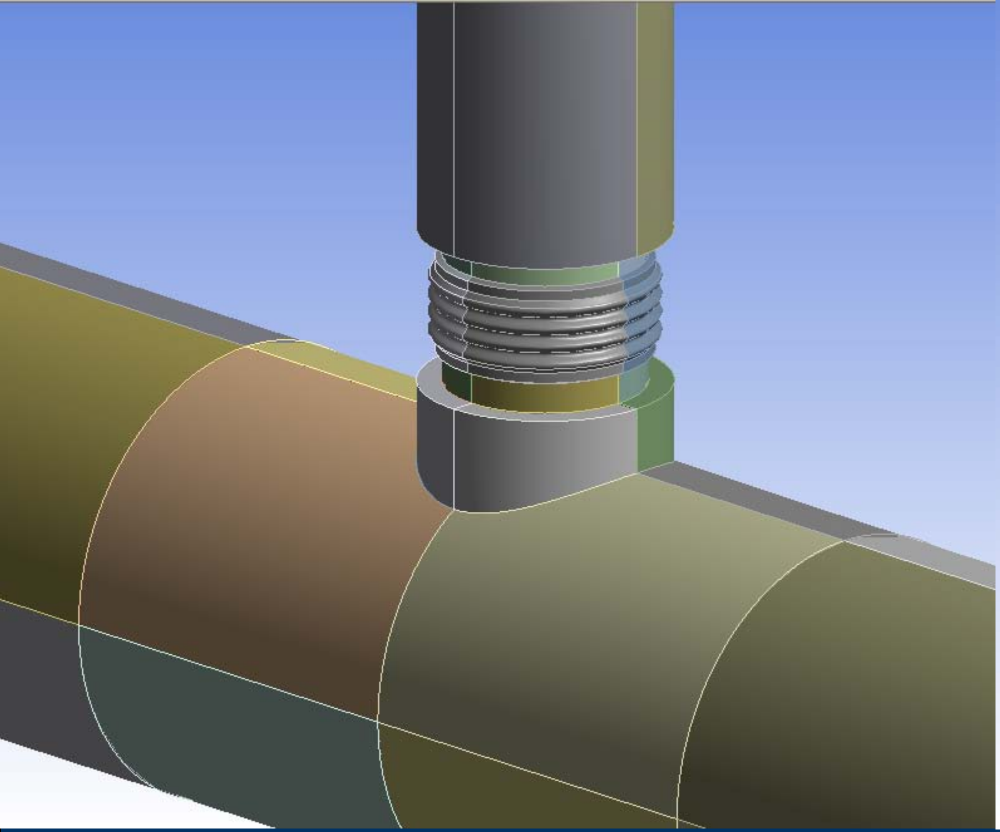

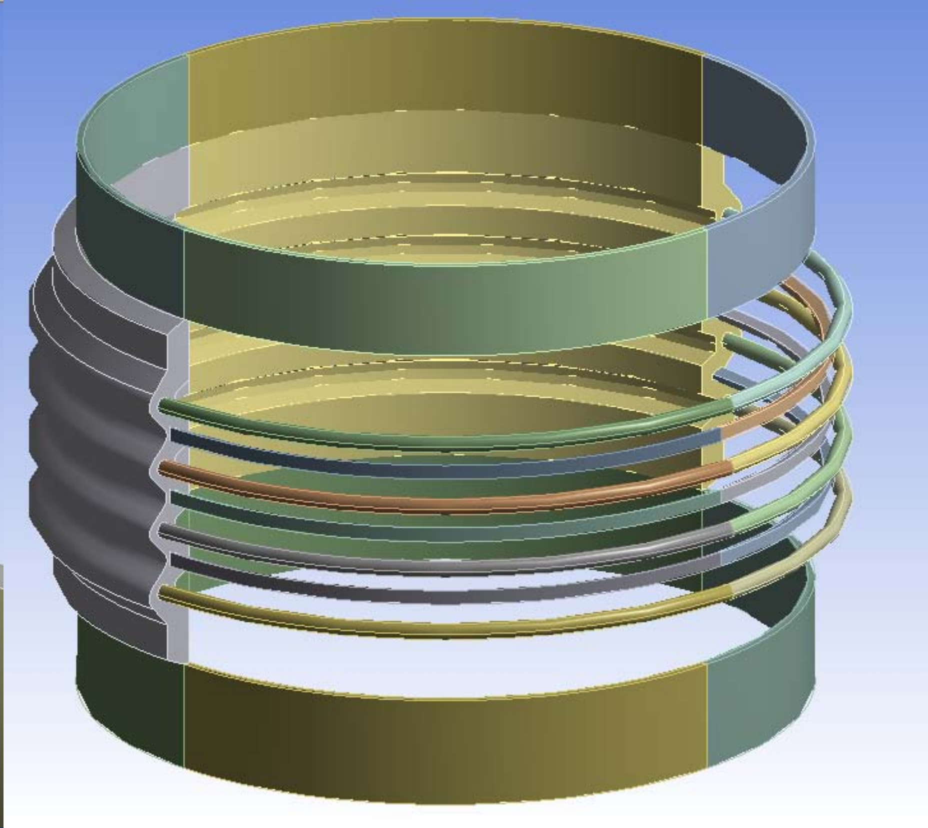

Study on the Response of Joint of Large Diameter Pipes Caused by Earthquake

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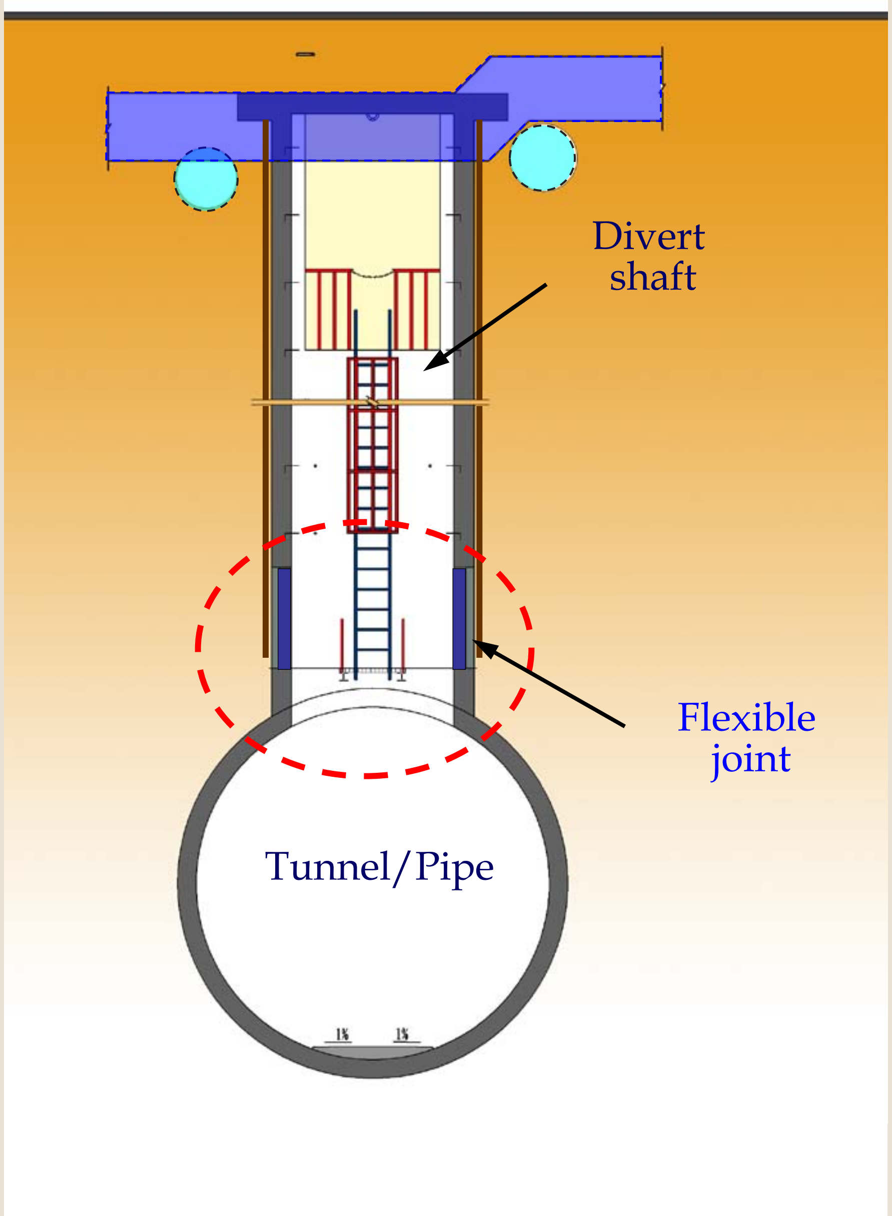
Jerry Jwo-Ran Chen

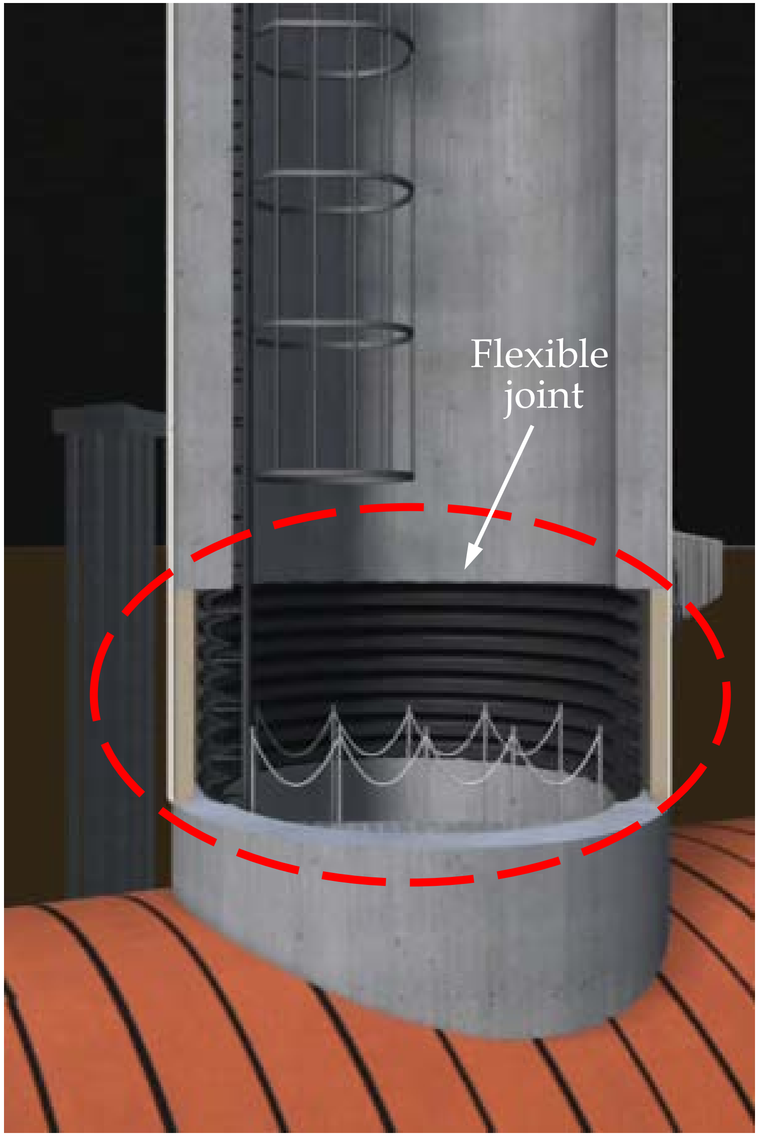
Flexible Joint



3.2 分歧井設於潛盾隧道正上方案例

- 分歧井設於潛盾隧道正上方
  - 免設置隧道橫坑
  - 避免橫坑施工造成砂湧
  - 降低施工費用
  - 縮短工期

- 分歧井與隧道連接採可撓伸縮管
  - 提高結構接頭耐震性能
  - 防止差異沉陷造成接頭損壞



可撓伸縮管

可撓伸縮管規格

- CNS 2473一般結構用軋鋼料SS400(SS41)鋼材
- CNS 10774自來水管件用橡膠製品
- 內徑240cm
- 高度185cm
- 試驗壓力15kgf/cm^2
- 變位量20cm
- 伸長量10cm，壓縮量5cm

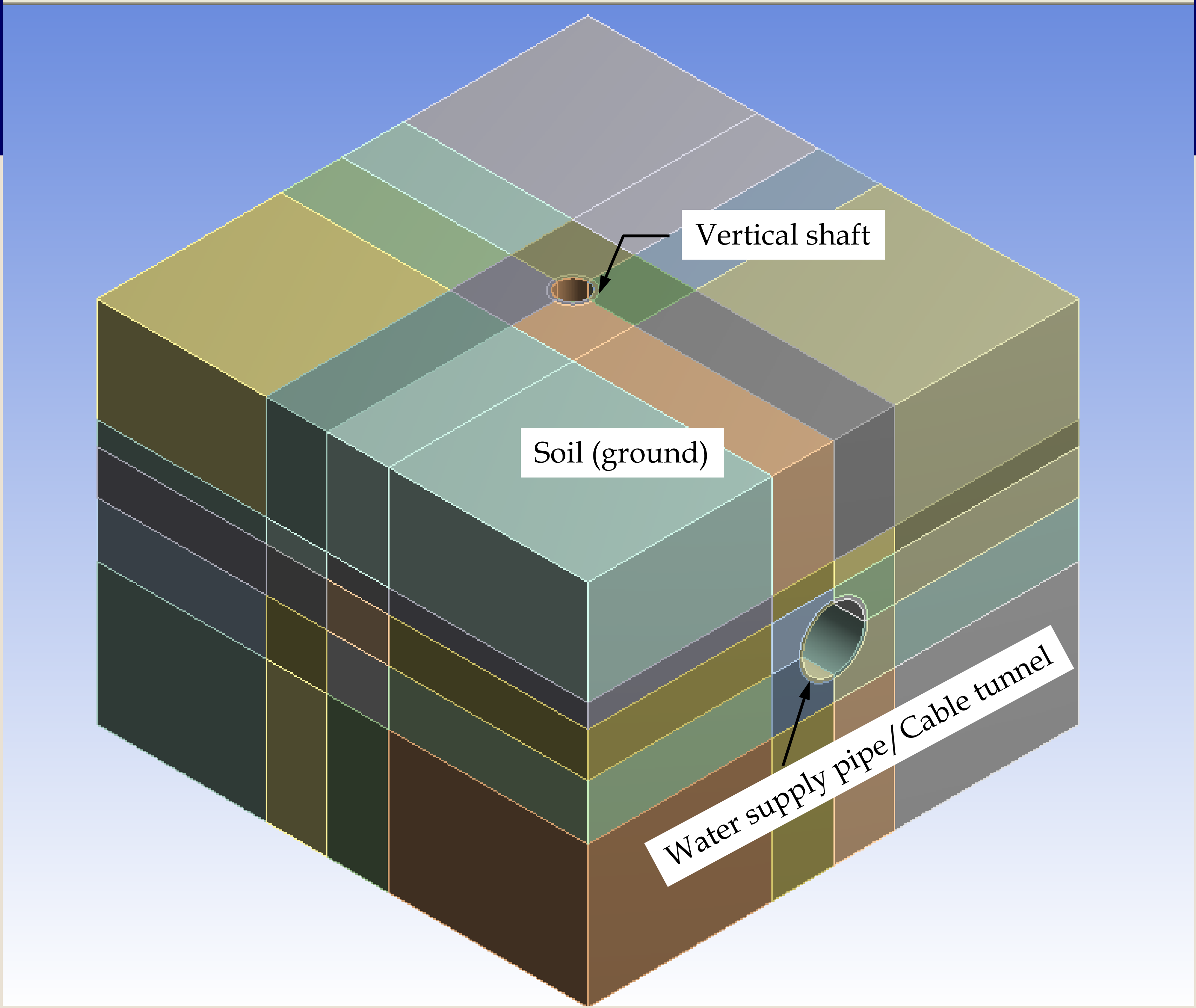
Content

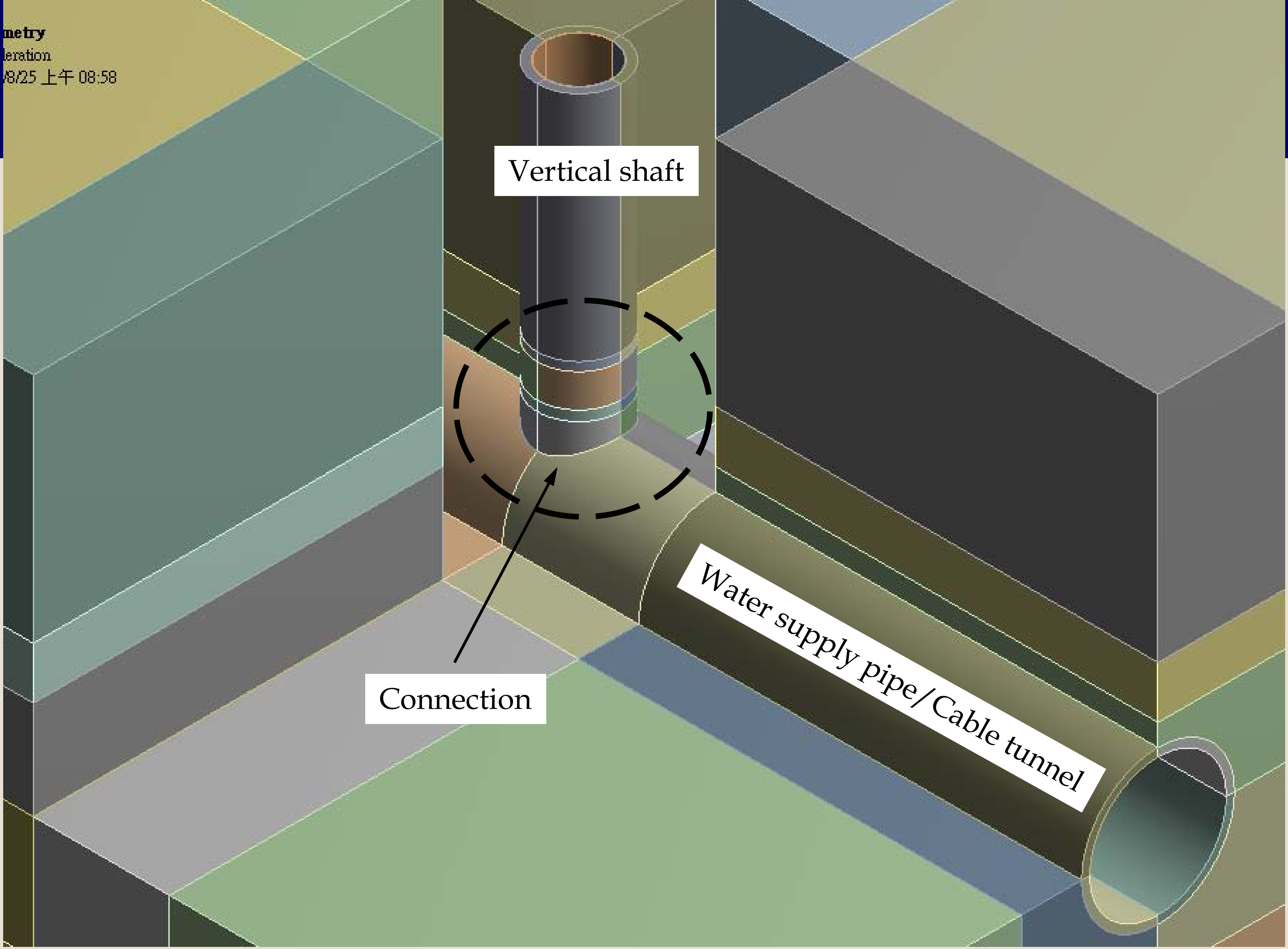
- Introduction
- Soil and Structure Interaction
- Elastic Modulus and Rayleigh Damping
- Boundary Condition
- Engineering Parameters for Numerical Analysis
- Geometry Mesh for Numerical analysis
- Results of Numerical Calculations
- Conclusions

Introduction

- The inspections of tunnels or large pipes indicates that cracks or leakages often take place at the connection joints.
- Earthquake is generally acknowledged the most cause to lead to the cracks or leakages possible.
- Consequently, the dynamic response at connection joints during earthquake will be examined in this article.

- Connection joint gives an irregular shape so that the plane strain analysis is inappropriate for the numerical calculation.
- 3D FEM analysis in the time domain for the dynamic response of the connection joints will be studied.
- Dynamic response of ordinary connection joint and flexible connection joint is to be compared to understand how the flexible connection joint will behave.


Vertical shaft
Soil (ground)
Water supply pipe/Cable tunnel


metry
leration
/8/25 上午 08:58
Vertical shaft
Connection
Water supply pipe/Cable tunnel

Soil and Structure Interaction (SSI)

- The external force derived from ground motion due to earthquake will apply on the connection joint of pipes.
- The ground is not a rigid body so that the deformation of connection joint during the earthquake would affect the ground and the ground deformation will affect the connection joints again, that is so-called SSI.
- The ground substituted for springs is commonly adopted in most numerical analyses. The soil-structure interaction would not be generated if the ground is simply replaced by springs with no mass.
- In this article, soil and connection joint will be simultaneously considered in calculating the dynamical response during earthquake shaking.

Elastic Modulus

- The performance of dynamic elastic modulus (E_d) shall be taken into account if the loading exert on the soil faster.
- The relation between static and dynamic elastic modulus is

$$\frac{E_d}{E_s} = 1 \sim 3$$

- It belongs to a static elastic modulus (Es) if the evaluation is based on the undrained test (S_U) or SPT-N blow counts.
- The static elastic modulus (Es) shall adequately increase so as to simulate the dynamic response of connection joint. In this paper, twice as much of elastic modulus (Es) will be used in the numerical analysis.

Rayleigh Damping (1/2)

- The integral dynamical equilibrium equations with damping are given as following

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F\}$$

- [C]: damping matrix
- The Rayleigh damping is defined by $[C]=\alpha[M]+\beta[K]$
- α,β : the proportional constant and are defined as

$$\alpha=\xi_i\cdot\omega_o \qquad \beta=\xi_i/\omega_o \qquad \xi_i=\frac{\alpha}{2\omega_i}+\frac{\beta\omega_i}{2}$$

  - ω_o : fundamental angular frequency
  - ξ_i : the damping ratio. For the saturated soil, the damping ratio is about 16%~19%.

Rayleigh Damping (2/2)

- One nature frequency of ground has to be input for calculating the α,β
- A modal analysis of the integral structure has been carried out to obtain the nature frequency of ground
- The lowest period of the first modal for the entire structure is T=0.96347.
- Usually the damping ratio of soil ground is about $\xi = 0.12$, then $\alpha = 0.7319 \quad \beta = 0.0196$
- Once the mass and stiffness of the entire structure are given, the Rayleigh damping will be defined as well.
- Rayleigh damping occupies no any room of computer memory that is the most advantage of Rayleigh damping employed in the finite element analysis.

Boundary Condition (1/2)

- The reflection and refraction of the seismic wave will take place at the man-made cut boundary that may produce an impermissible error.
- Lysmer (1972) propose setting up a damping on the artificial boundary to eliminate the extra stress exerting on the flexible connection joints again.
- The artificial damping on the boundary where Lysmer proposes basically has no wave energy to reflect.

$$\sigma = a\rho V_P \dot{\omega} \qquad \tau = b\rho V_S \dot{u}$$

  - σ, τ : normal stress / shear stress on the damping boundary
  - $\dot{\omega}, \dot{u}$: normal/tangential velocity component

Boundary Condition (2/2)

– V_s, V_p S-wave velocity/P-wave velocity

$$V_S = \sqrt{\frac{G}{\rho}} \qquad V_P = \frac{V_S}{S} \qquad S = \sqrt{\frac{1-2\nu}{2(1-2\nu)}}$$

- The spring damper of combined element-14 of ANASYS element library is adopted to exert on the boundary.
- The spring damper element is defined by two constant, spring constant (k) and damping coefficient (C).
- The spring constant (k) : multiplication of subgrade reaction coefficient of ground and the dimension of area where the combined element-14 is installed.

Engineering Parameters for Numerical Analysis (1/2)

- The dynamic response of the entire structure is much associated with the material parameters.
- The elastic modulus of steel, concrete and rubber can be obviously gained from laboratory test.
- The elastic modulus of soil is much scatter in comparison with the steel.

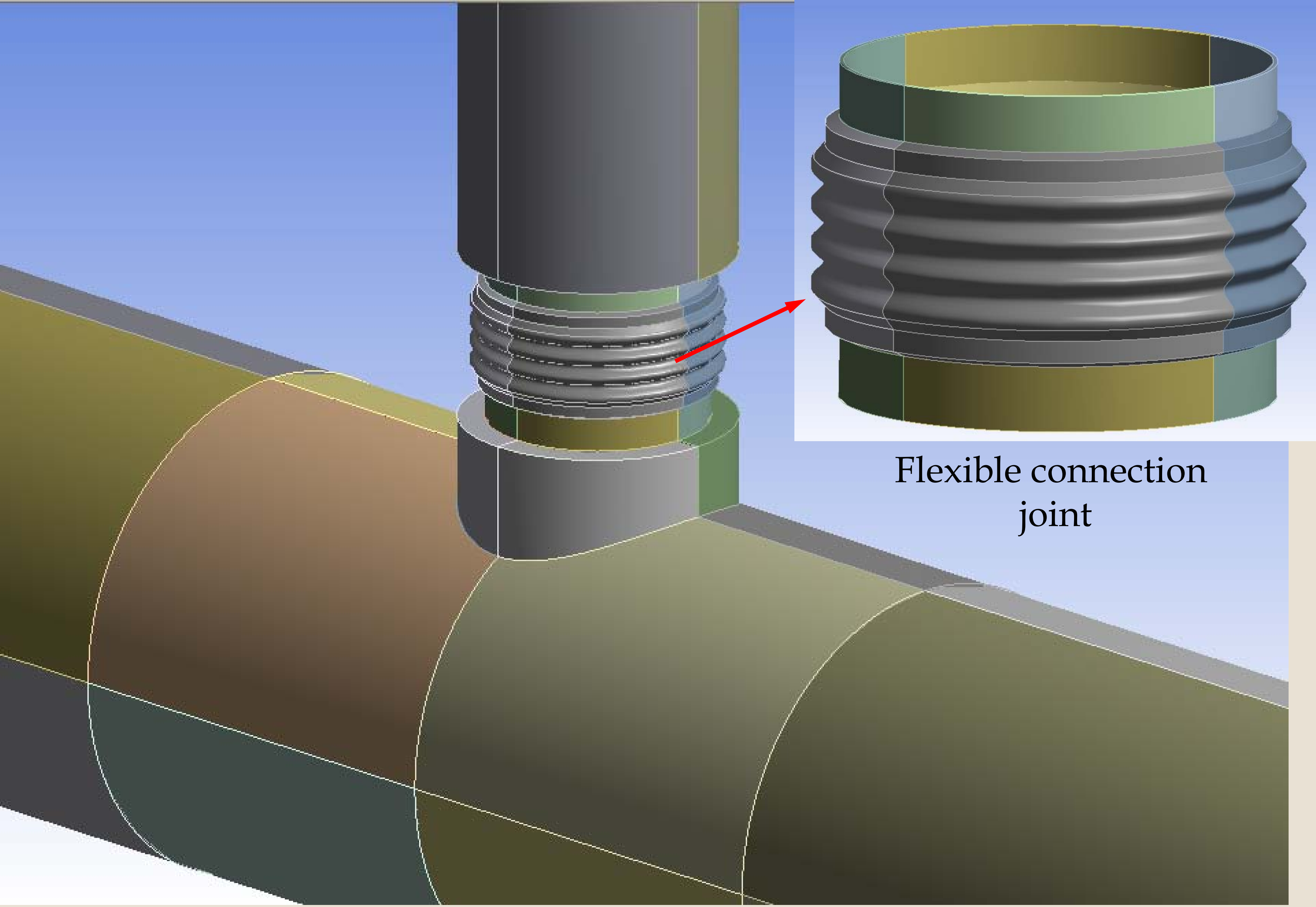
$$E = 2000 \cdot N \ \ (\mathrm{kPa})$$

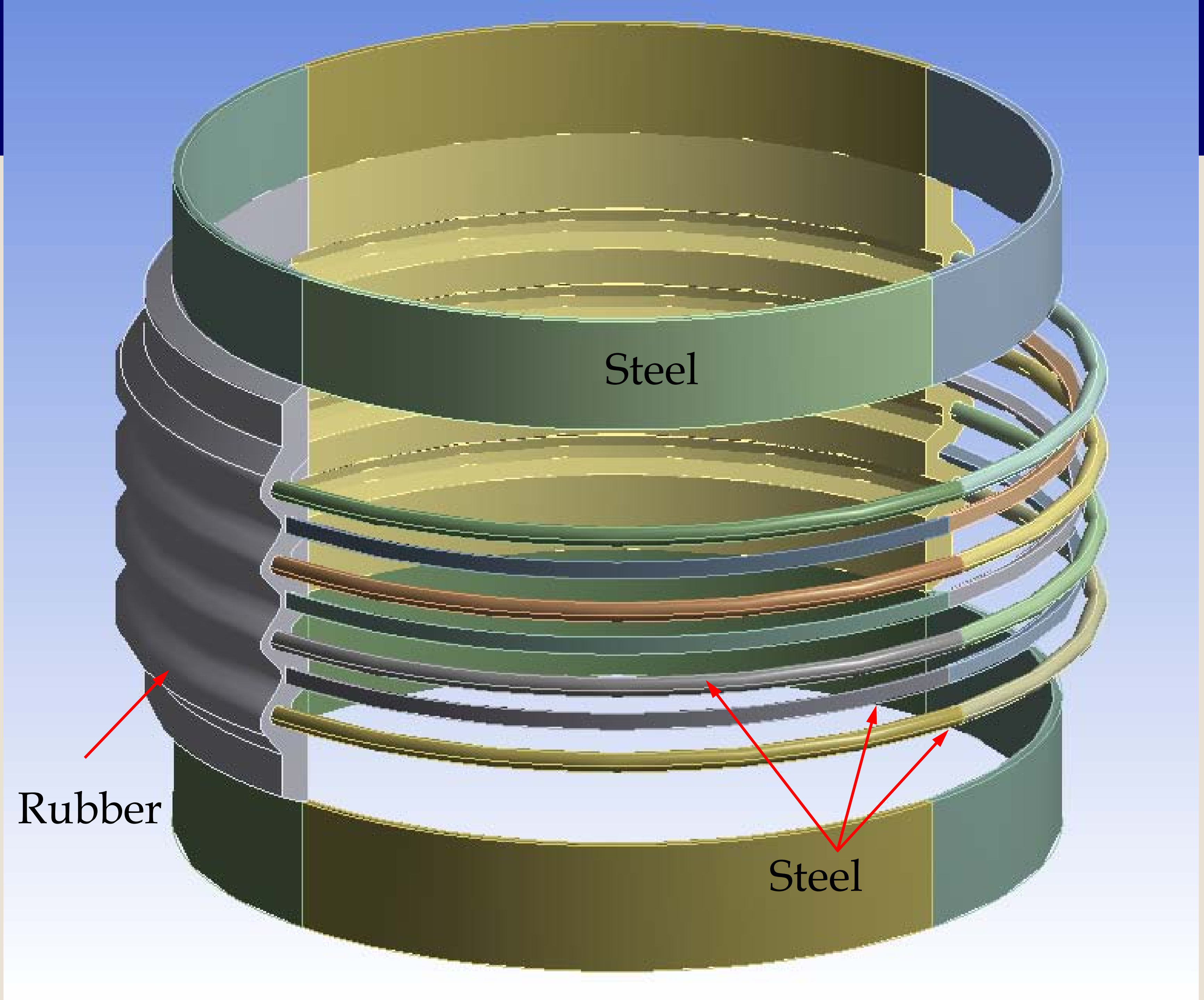
  - N represents the SPT blow counts.
- Attention has to be paid that elastic modulus has to increase twice as much of elastic modulus (Es) when the dynamic response is concerned in the numerical analysis.

Engineering Parameters for Numerical Analysis (2/2)

- the engineering parameters adopted in this numerical analysis can be summarized as show in Table-I.

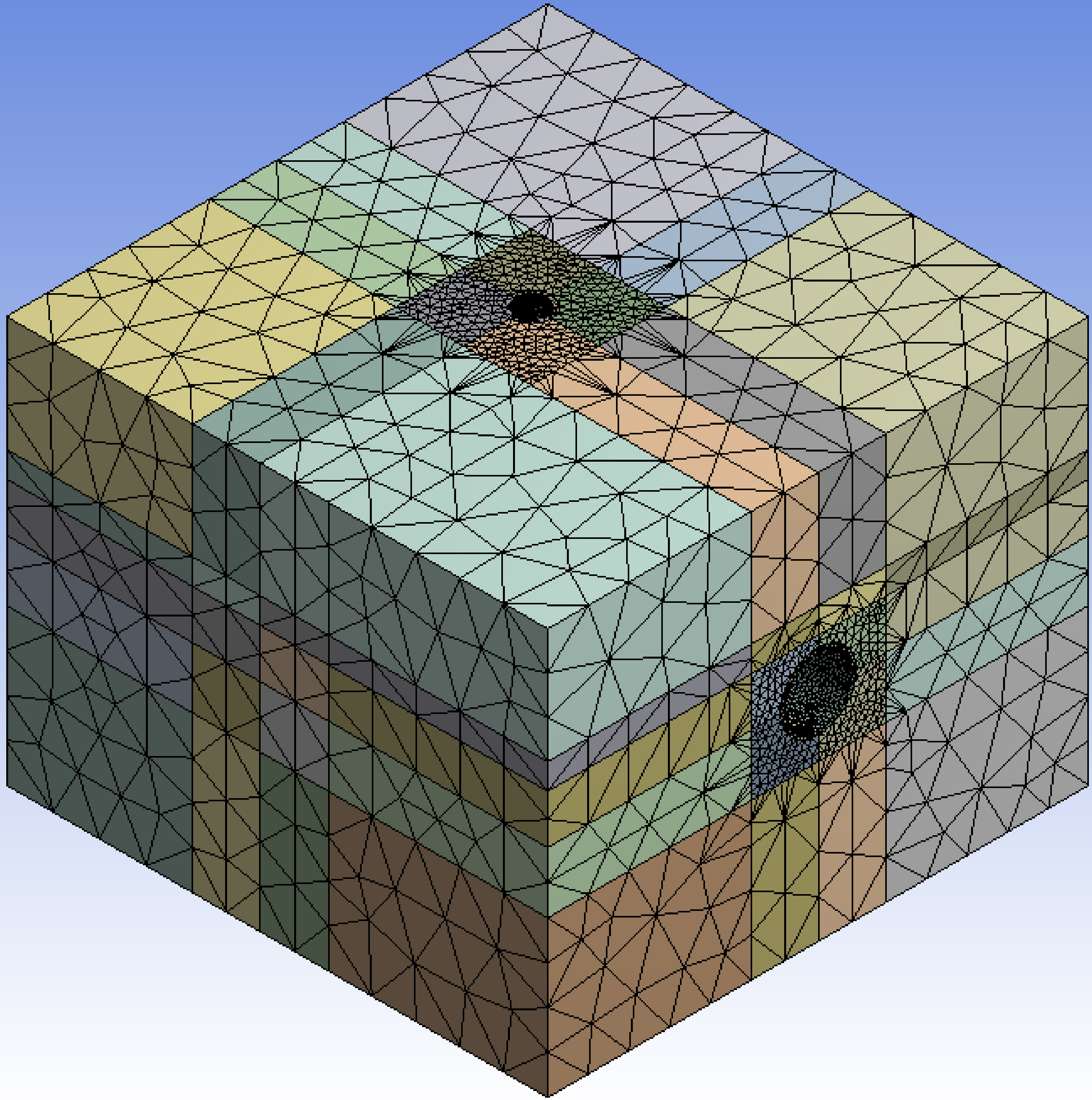
Materials	SPT-N	Elastic modulus (kPa)	Poisson ratio (ν)	Density (kg/m^3)
Steel	-	2.1×10^{8}	0.3	7800
Concrete	-	2.1×10^{7}	0.17	2400
rubber	-	5.0×10^{4}	0.48	1500
Sandy soil	15	3.0×10^{4}	0.32	2000

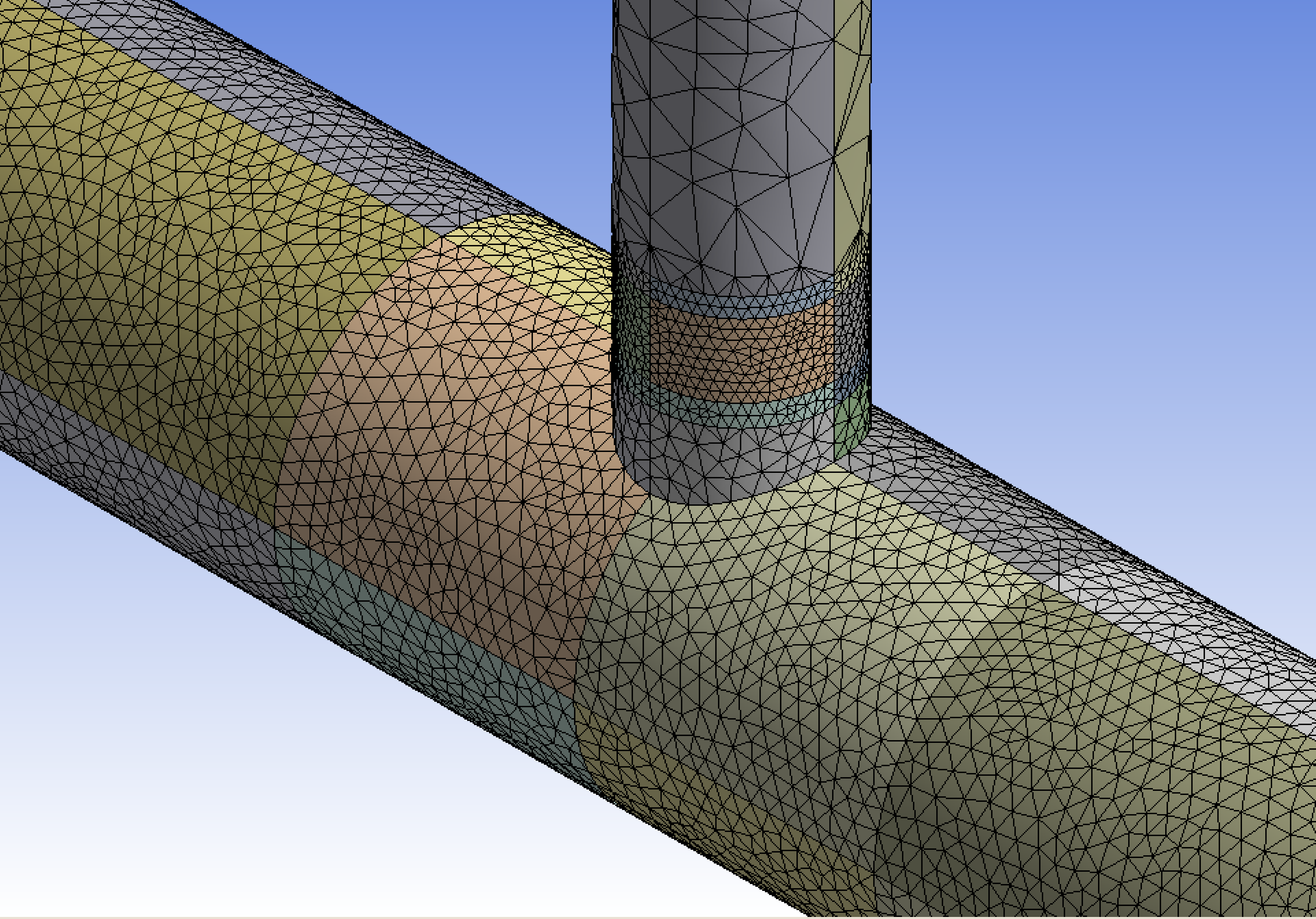

Flexible connection
joint

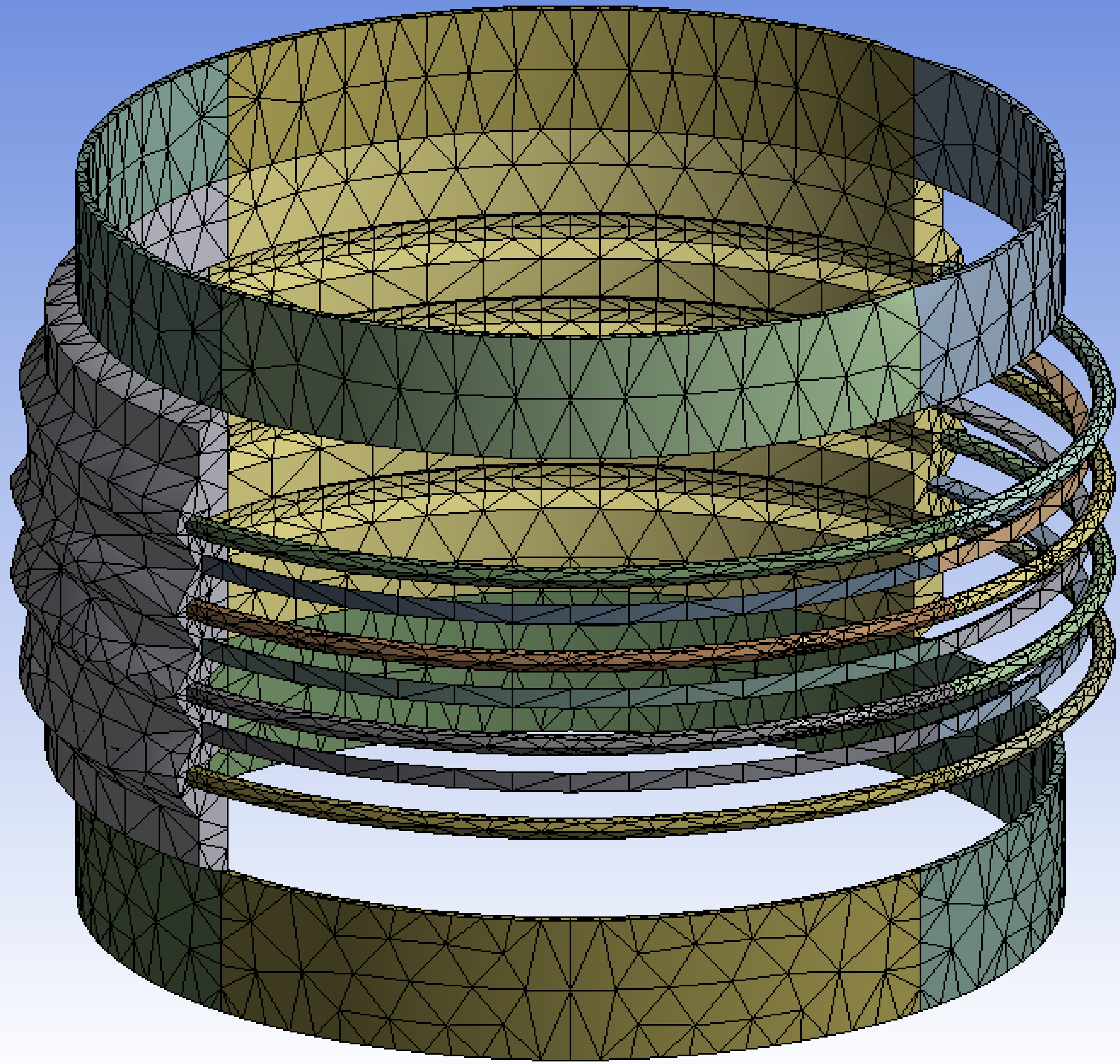

Steel
Rubber
Steel

Geometrical Mesh (1/2)

- The ground mass plays an important role in the earthquake so that the ground cannot be simply substituted for springs with no mass in the numerical analysis.
- The flexible connection joint consists of mainly rubber and some steel ribs.
- The geometrical shape of the entire structure, including the flexible joint and the ground, are so complicate that the amount of the continue mesh is more than 200 thousands that is a huge calculation and is also very time consuming.
- It is near impossible to obtain the results in the transient time domain analysis.

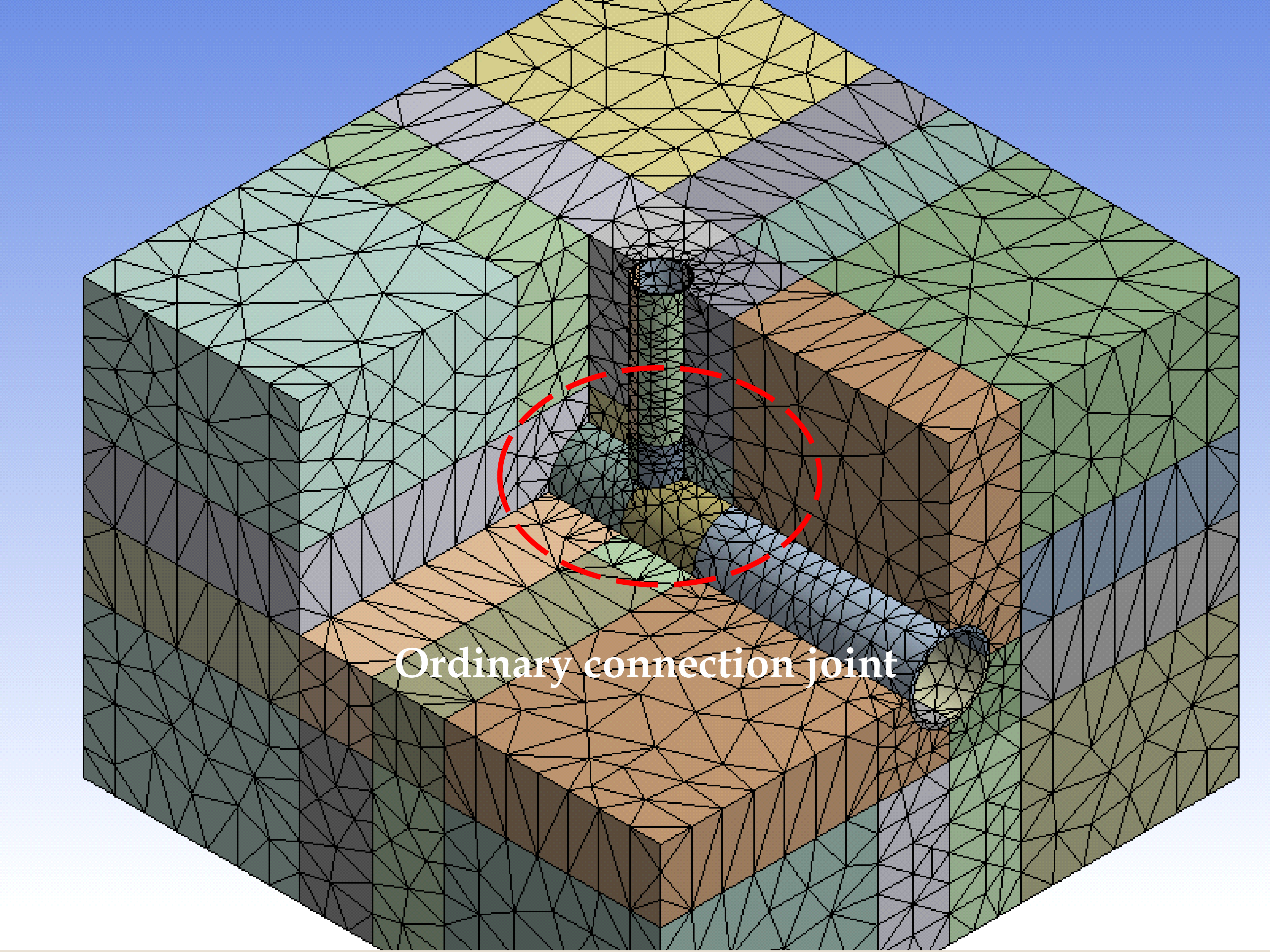


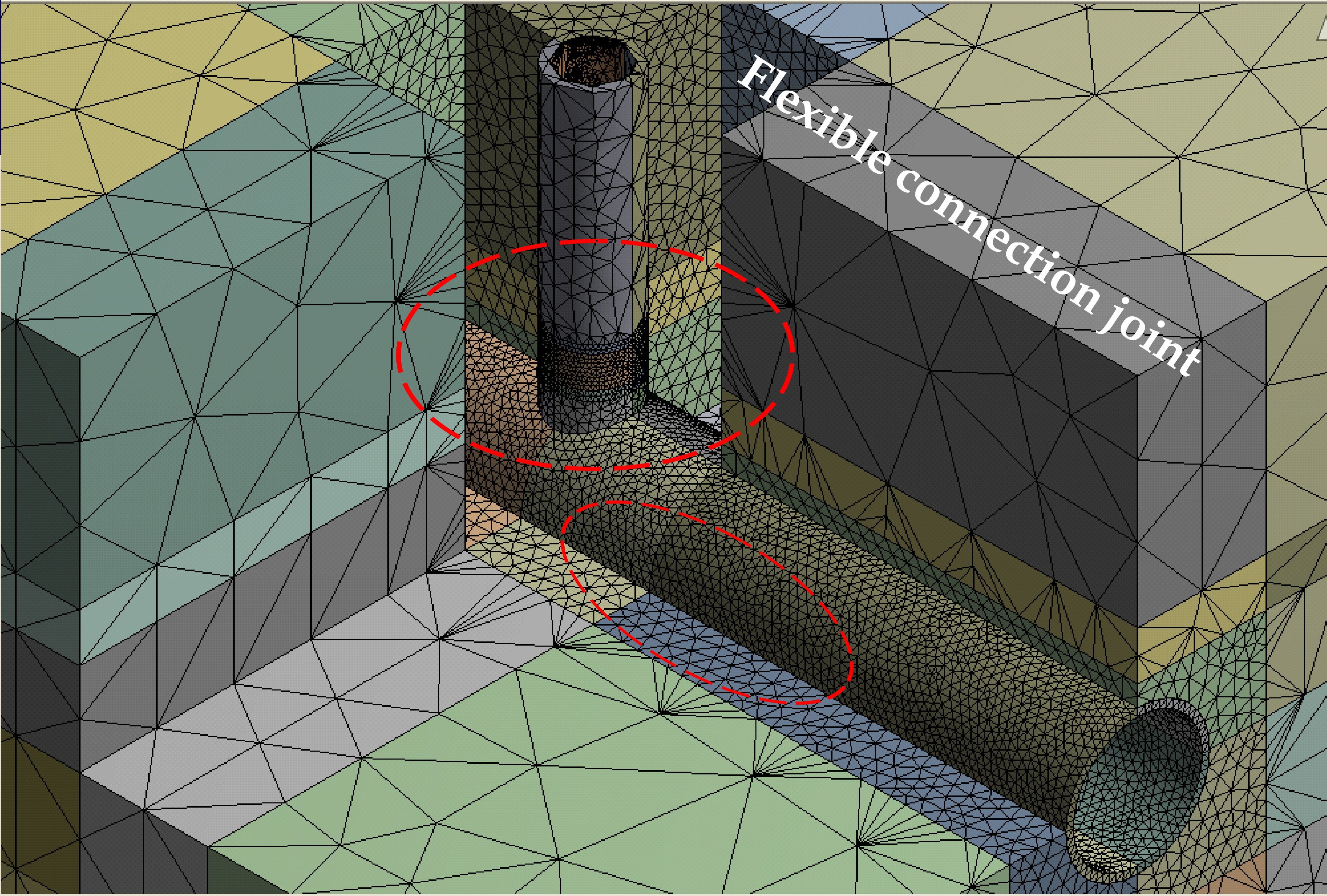




Geometrical Mesh (2/2)

- Two parts, ground and pipes, have been suggested to mesh independently from one another to reduce the mesh amount.
- The contact technique has to be implemented to tie these two parts before carrying out numerical calculation. Even so, there are around 30 thousand elements and 70 thousand nodes in this FEM calculation.

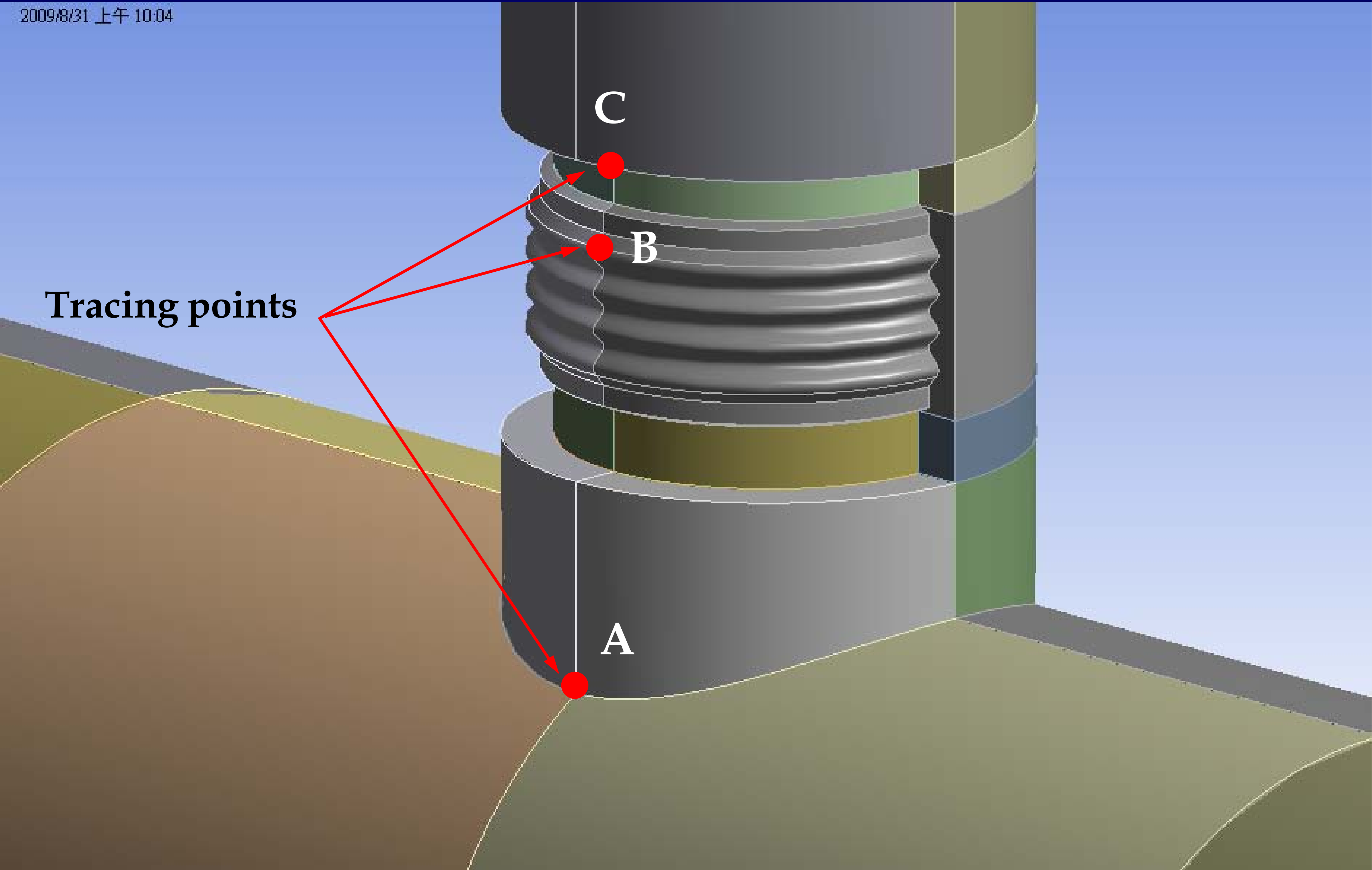

Ordinary connection joint


Flexible connection joint

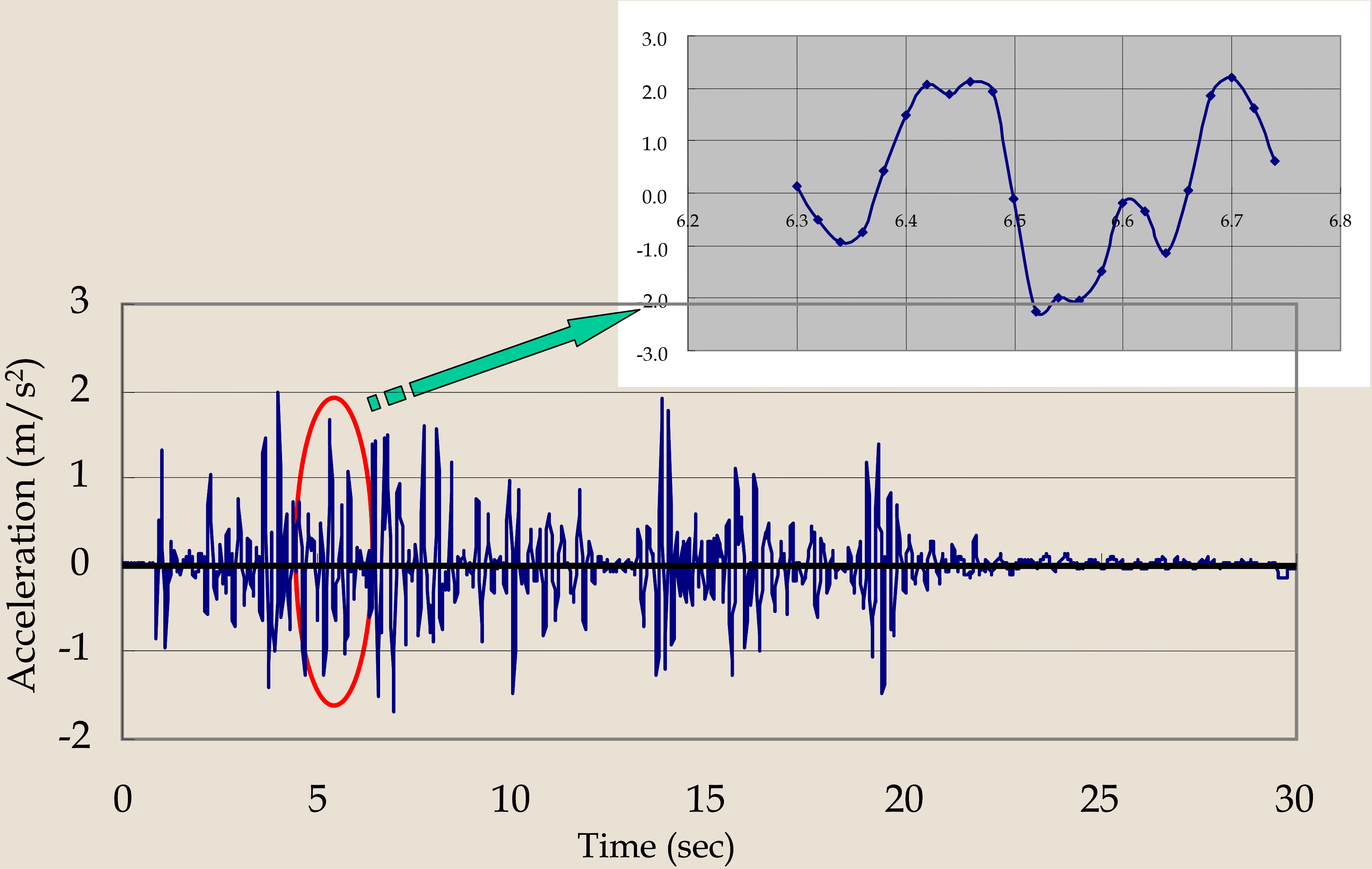
Results of Numerical Analysis (1/5)

- The time duration of an earthquake shaking may reach 80 seconds, depending on magnitude of earthquake
- The history of earthquake is in 200 record/sec.
- It is huge data to be calculated when carrying out the time domain transient FEM analysis.
- Only part of the time history record of earthquake is possible to be calculated in the FEM analysis.
- Even so, the calculating results occupy the hard disk more than 25GB in this numerical calculation.

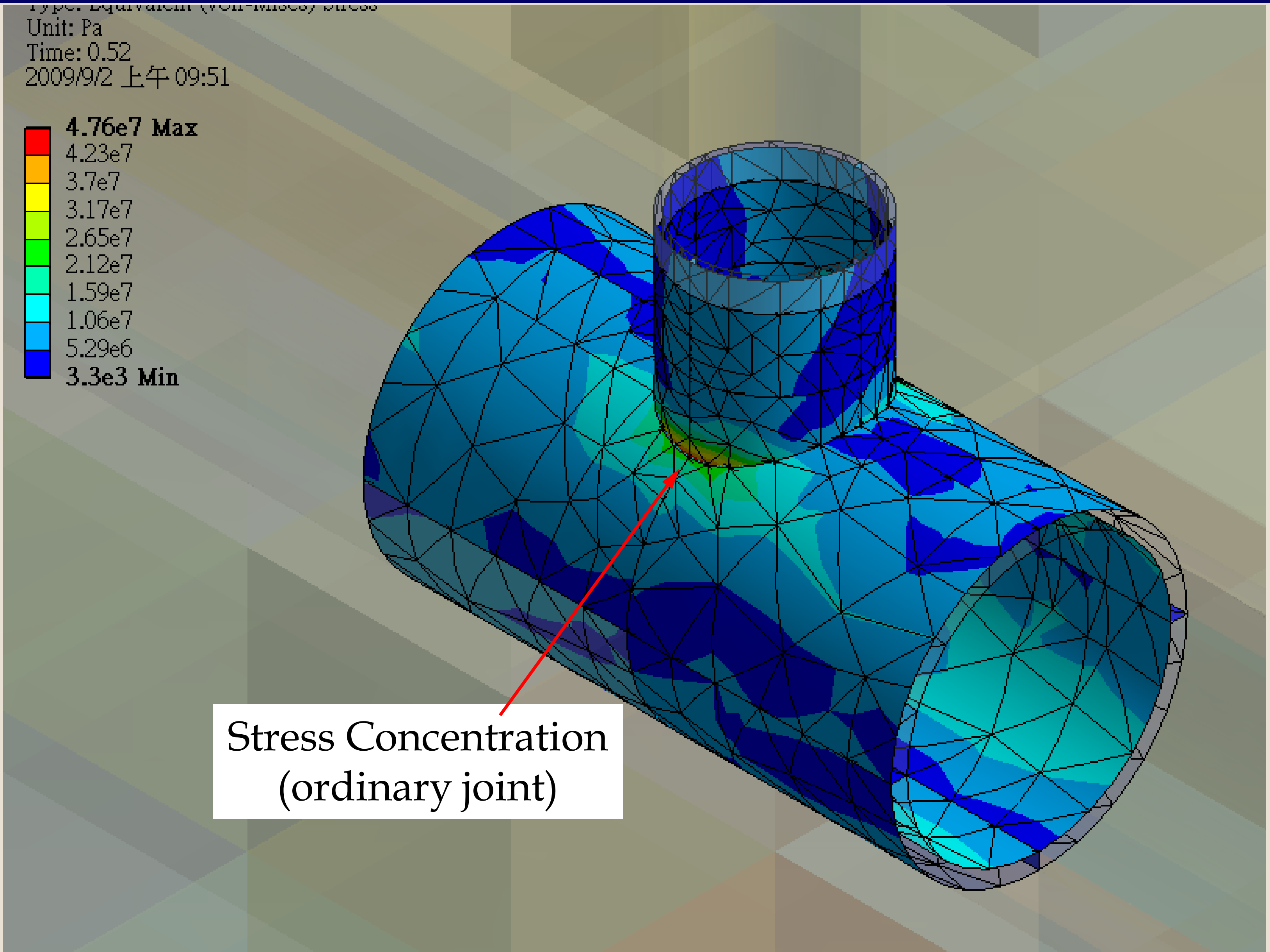
Location of Tracing Points



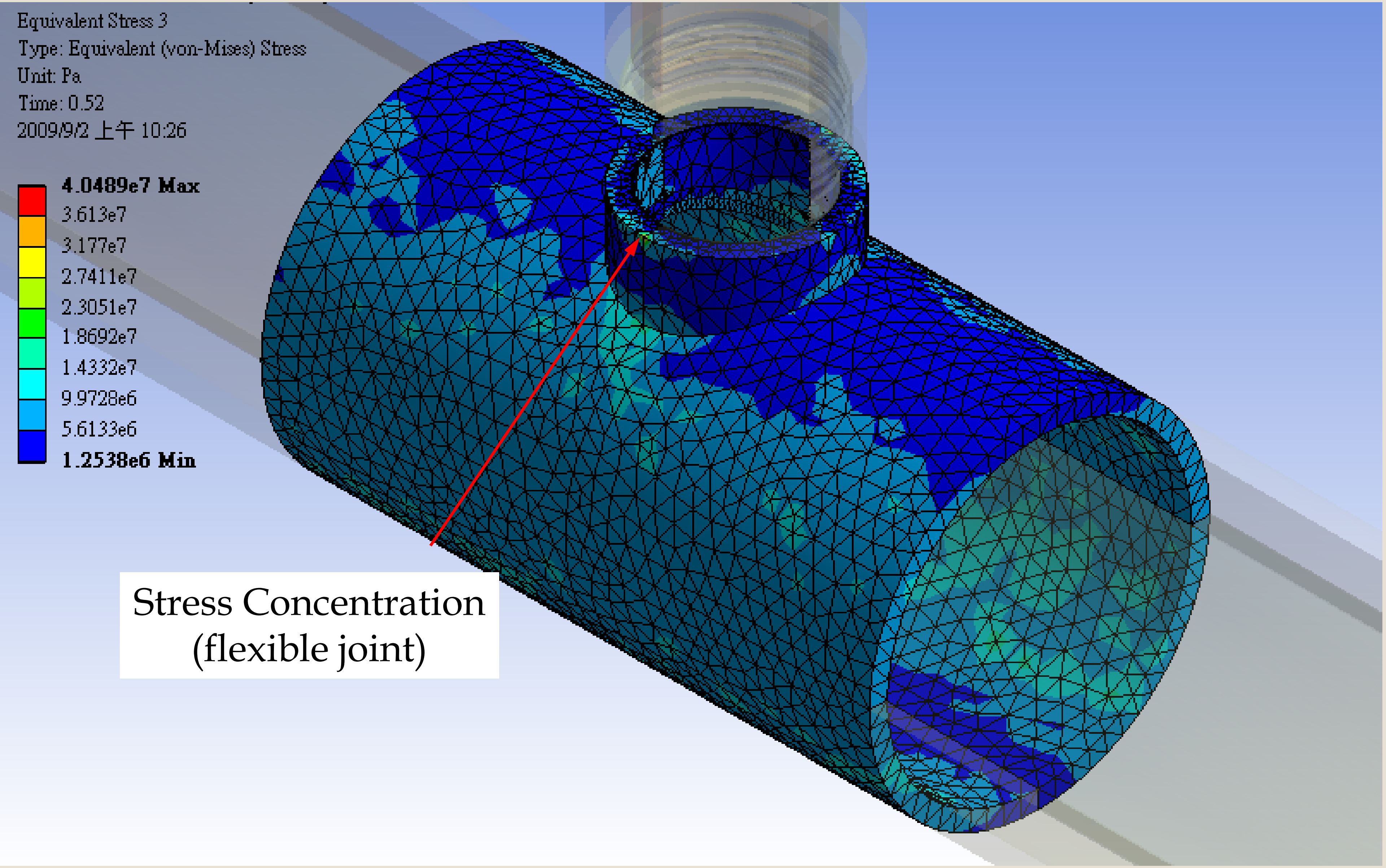
Acceleration Time history



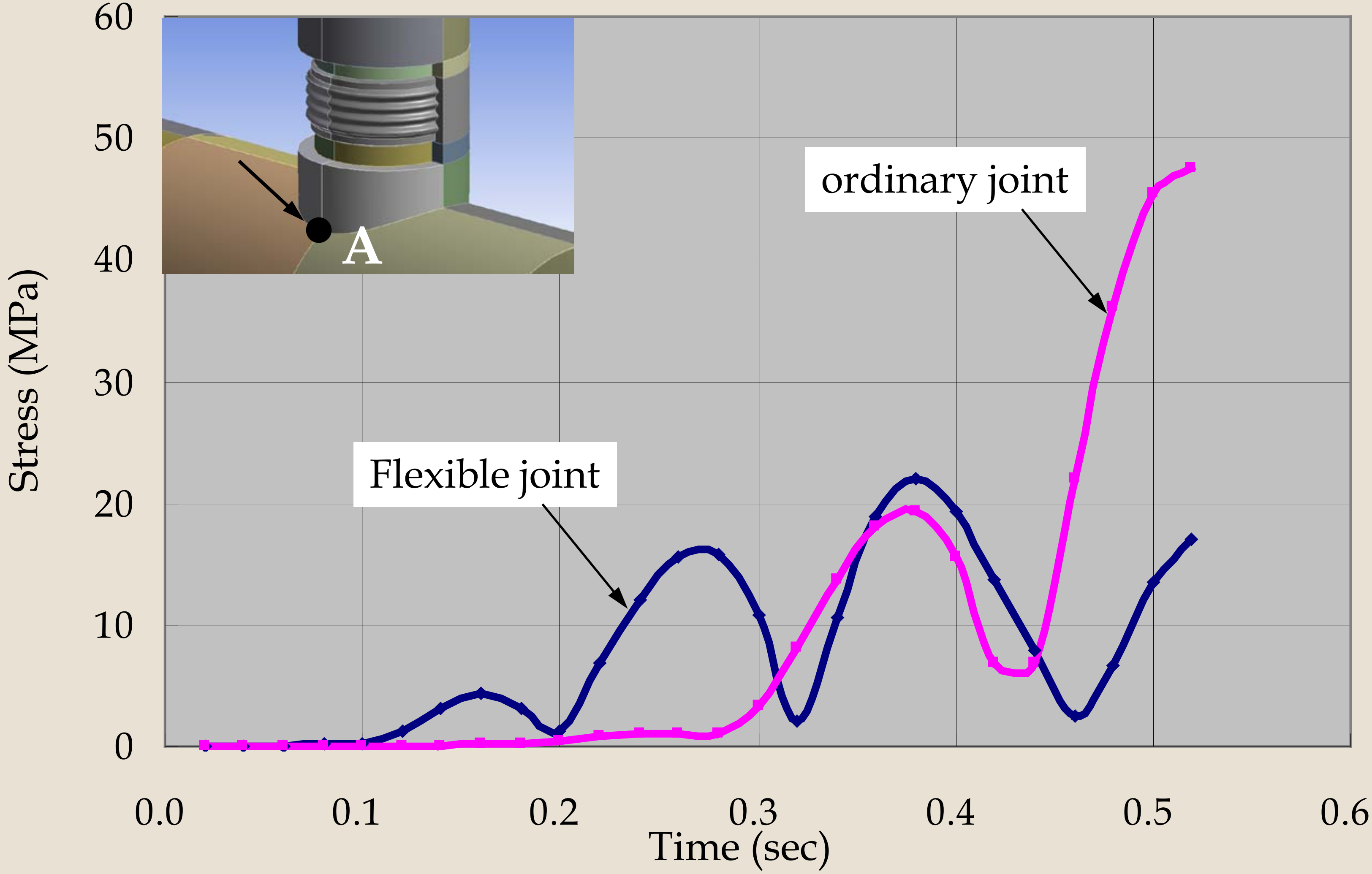
Contour of von Mises stress (2/5)



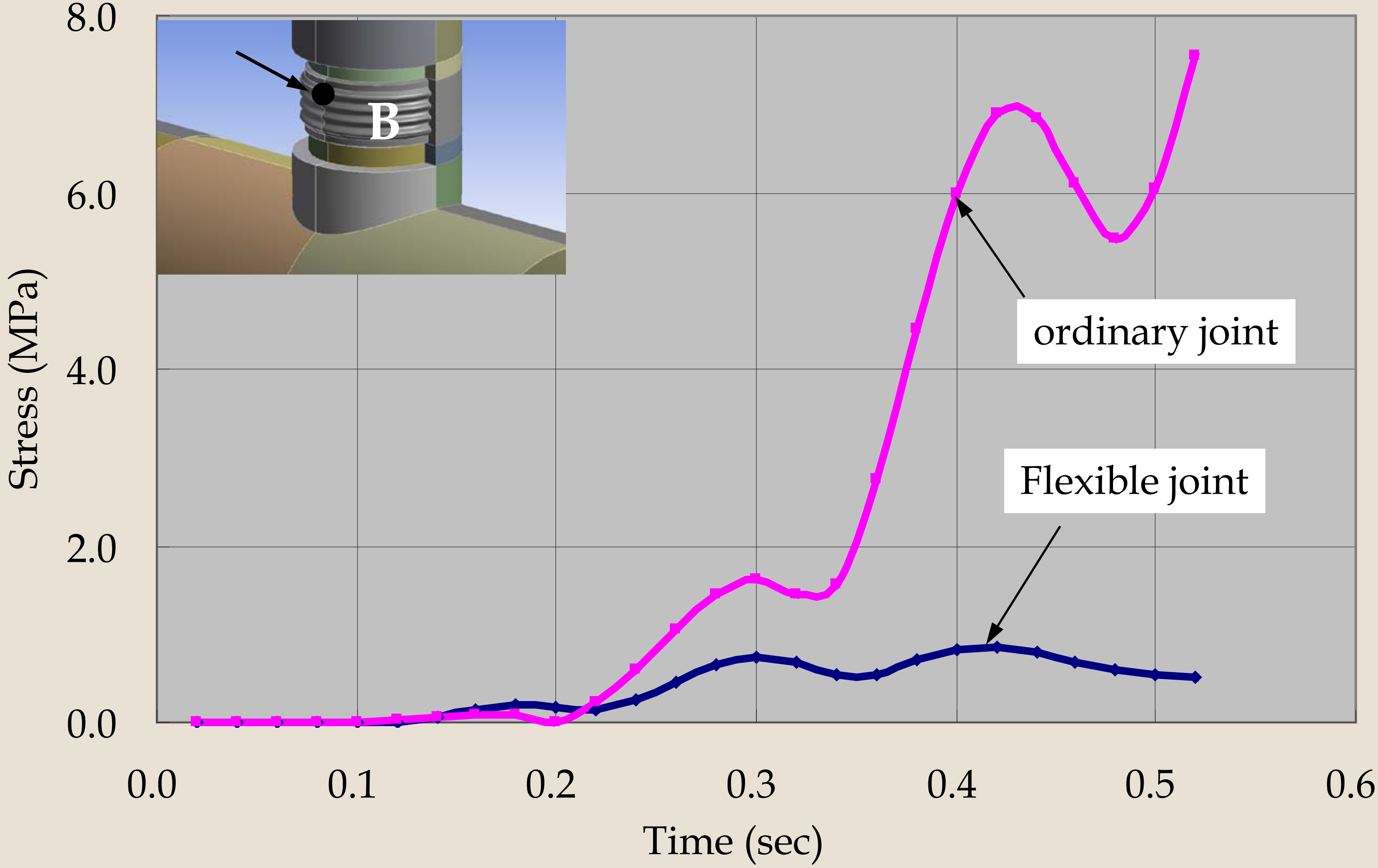
Contour of von Mises stress (3/5)



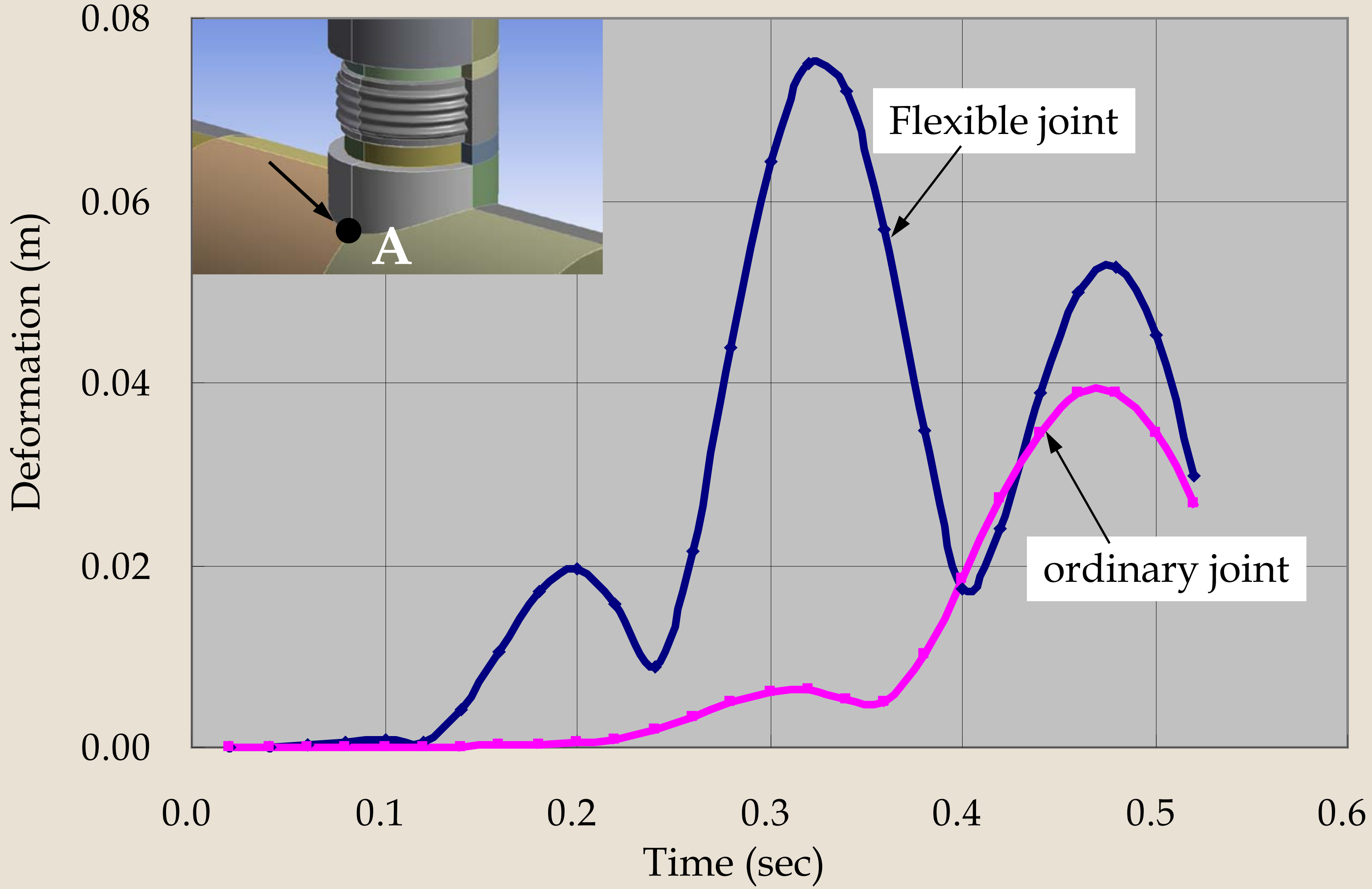
Response of stress history at A



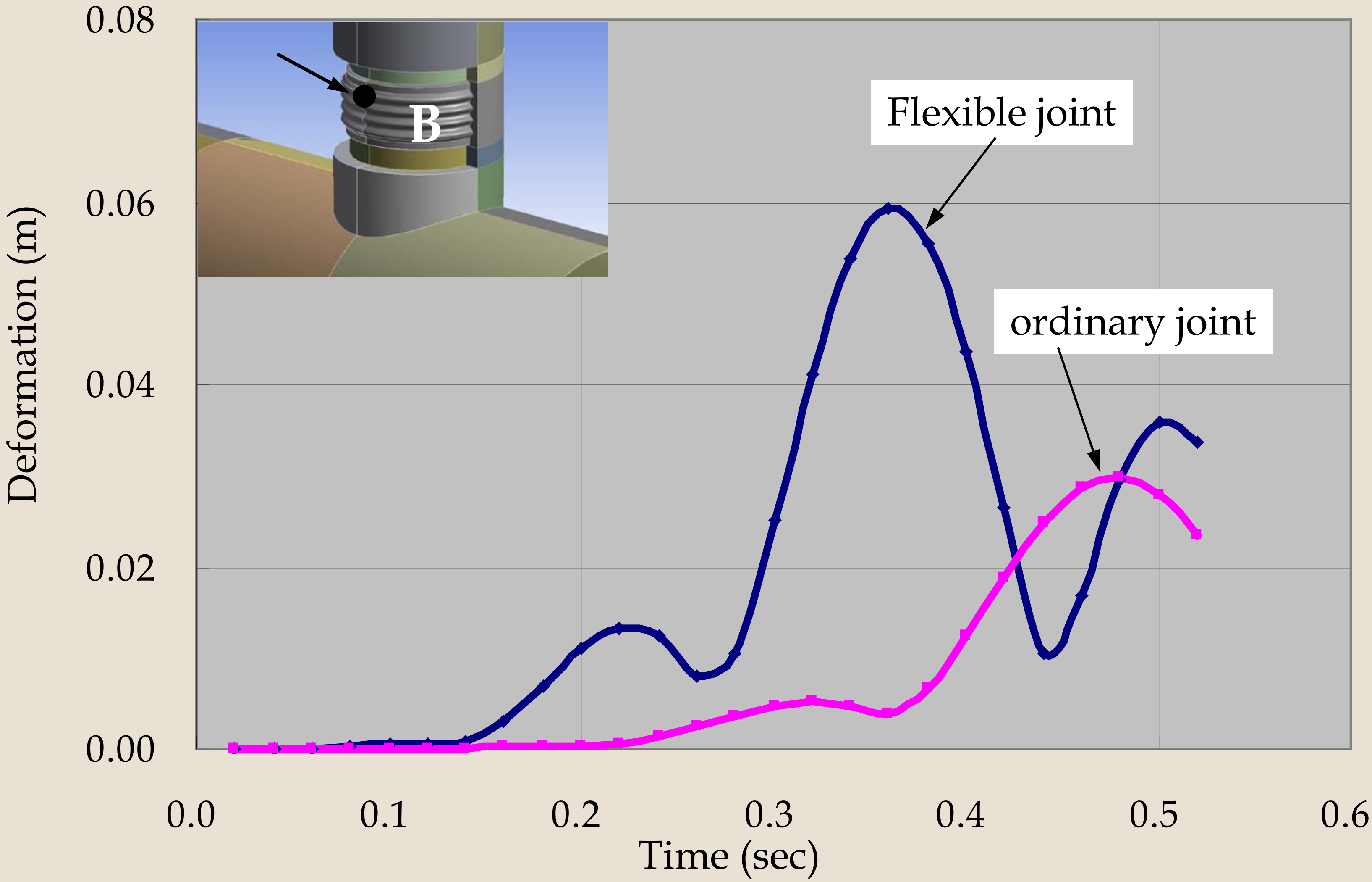
Response of stress history at B



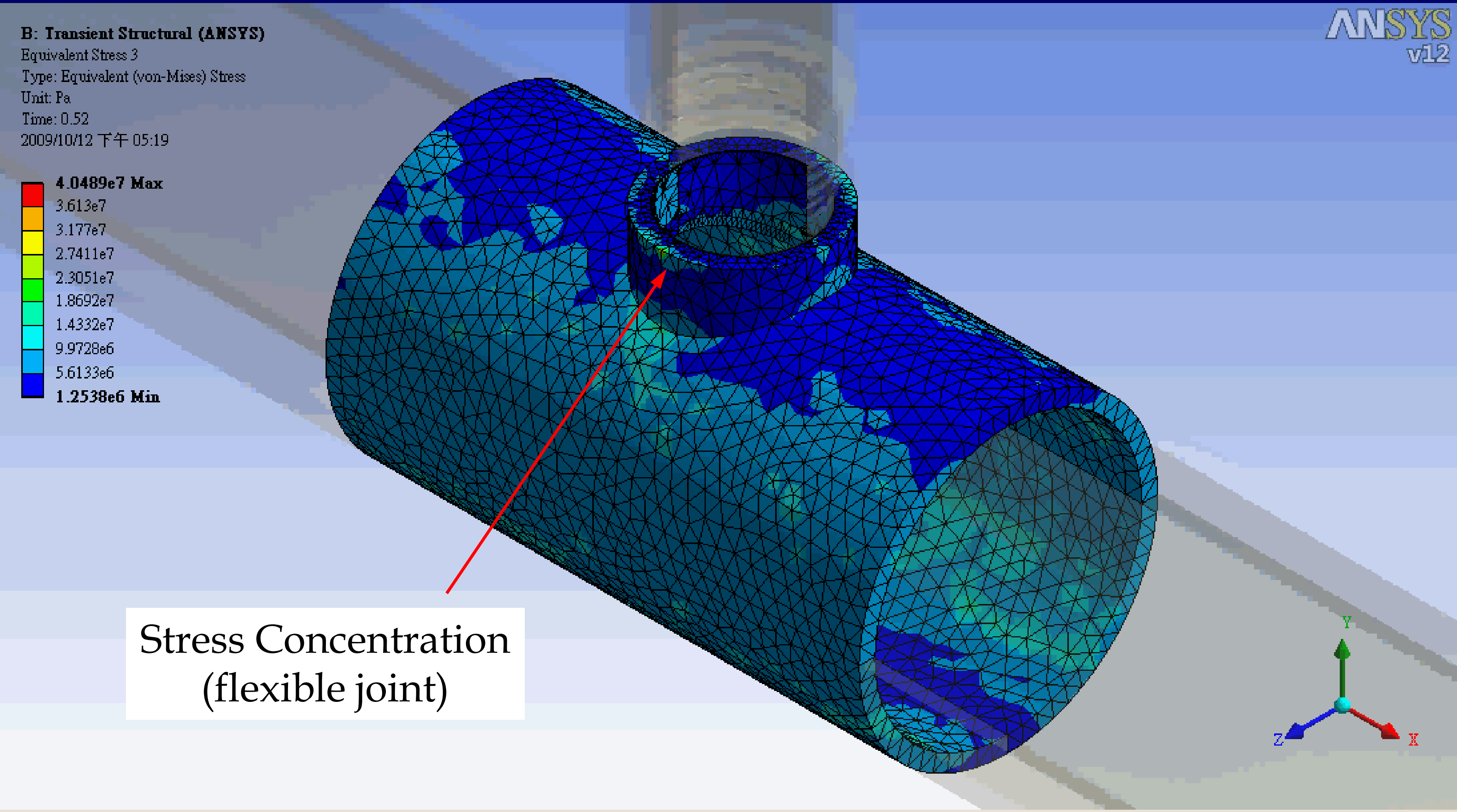
Response of displacement history at A



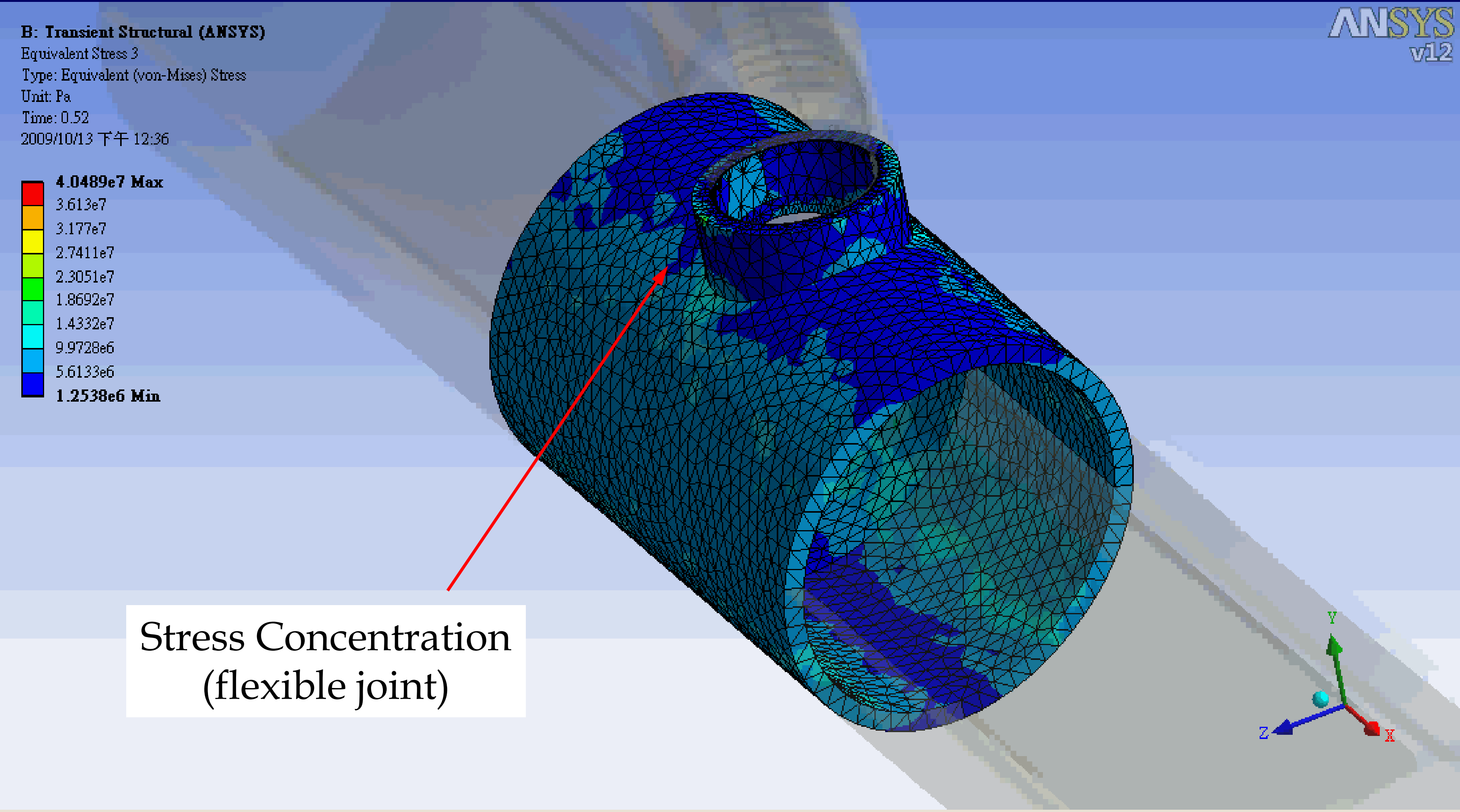
Response of displacement history at B



Contour of von Mises stress



Contour of von Mises stress



Conclusions (1/2)

- The Rayleigh damping of the entire structure is adopted in this study. The needed frequency ω for evaluating the Rayleigh damping constants α, β can be obtained by carrying out the modal analysis of the entire structure.
- The boundary damping for no wave energy to reflect can be roughly assessed by following the Lysmer suggestions.
- The spring damper of combined element-14 of ANSYS element library is employed to simulate the boundary damping in which the input of spring constant (k) and damping coefficient (C) shall be adequately adjusted to meet the functionality of no energy accumulation on the boundary

Conclusions (2/2)

- The stress concentration at the connection obviously takes place during earthquake shaking.
- The flexible connection joint results in a less stress concentration in comparison with that of which happens in the ordinary connection joint. On the contrary, the flexible connection joint will cause more displacement.
- The flexible connection joint will reduce the stress concentration with regard to the ordinary connection joint as the basis of reference.
- The flexible connection joint could avoid the crack and leakage during the earthquake shaking since only a less stress generation takes place.

Thank you for your attending

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