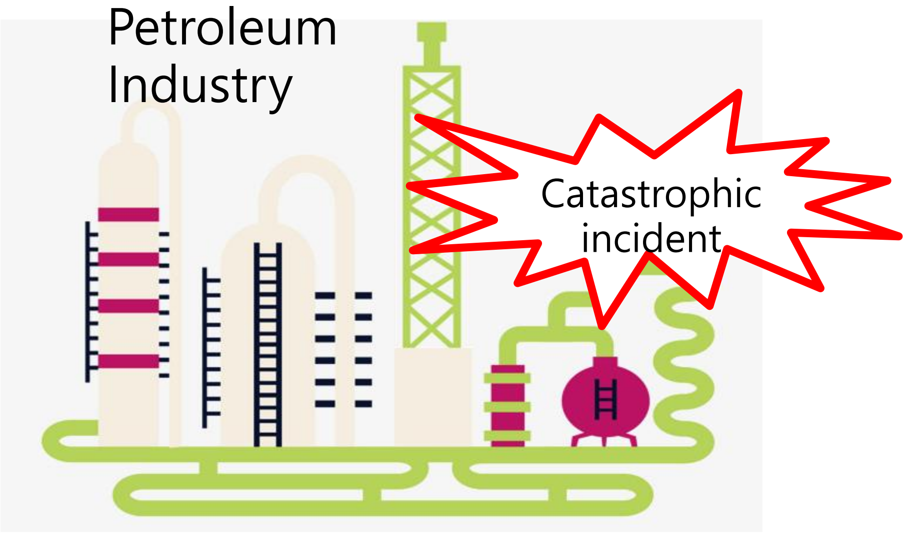
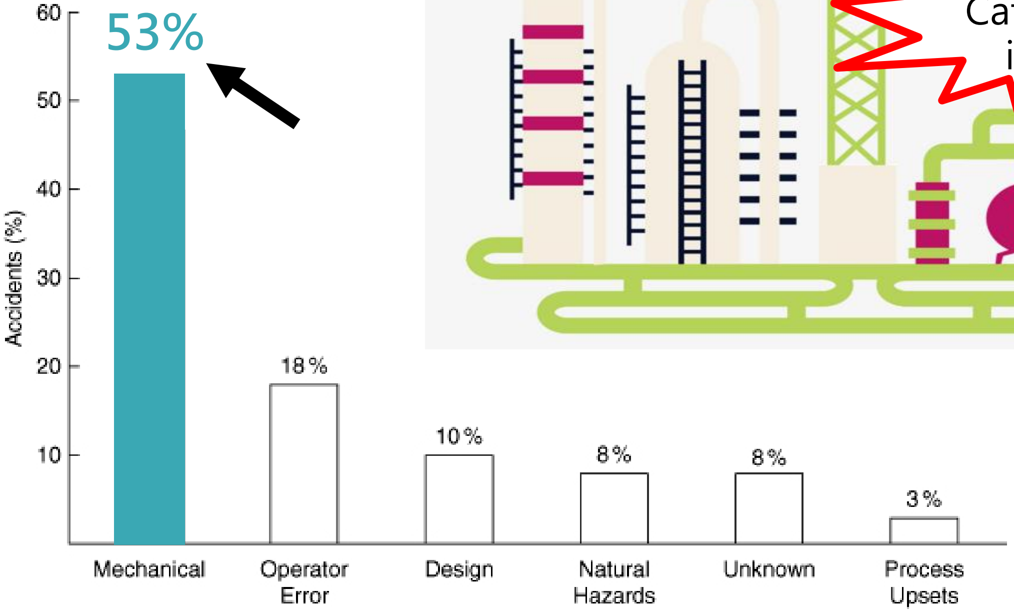
A Finite Element-Based Analysis Approach for Computing the Remaining Strength of the Pressure Equipment with a Local Thin Area Defect

Presenter: Yen-Ju Lu
Advisor: Prof. Chen-hua Wang

國立高雄科技大學
National Kaohsiung University of Science and Technology

The importance of petrochemical industry and equipment





(Chemical Process Safety - Fundamentals with Application, 2002)

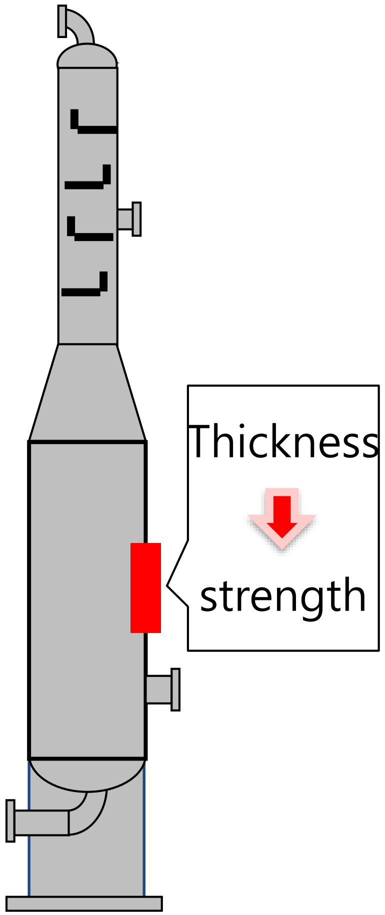
Property losses caused by catastrophic accidents are listed below :

- shutdown
- compensation
- penalize
- Environmental rehabilitation
- Other fees
- ...

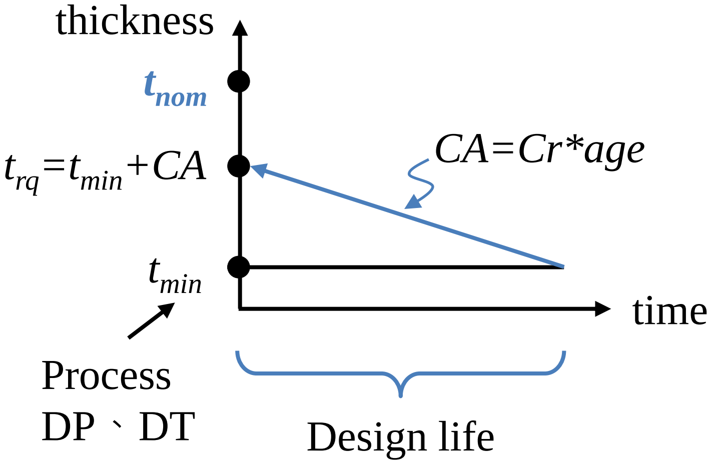
60% of them are caused by the breakage of static equipment.

- **Equipment** is the primary control object in disaster prevention operations
- **The problem with static equipment is mostly due to corrosion** or other degradation mechanism that causes the strength of equipment to fall below required strength.

thickness =strength



At Design stage



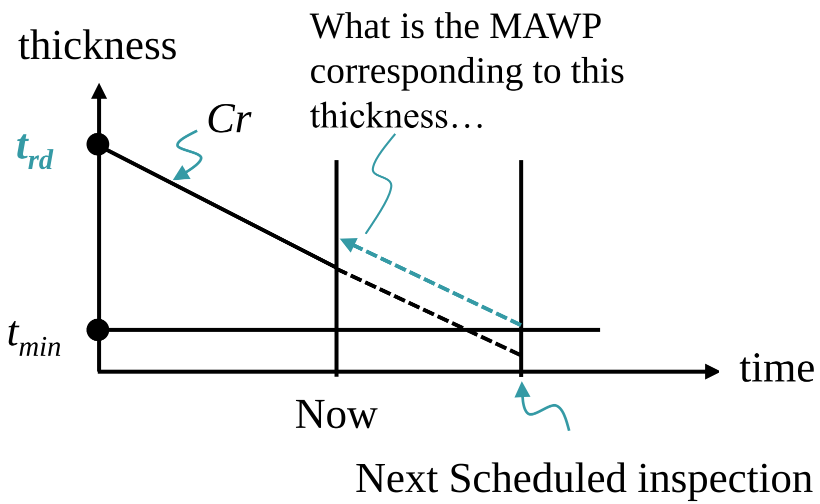
- tnom=closest commercially available spec of steel plate what thickness is larger that t_{min}+CA

Minimum required thickness at value the stress inside reach the allowable strength

Corrosion allowance for the operation life

- At end of life this CA is supposed to be eaten up and only the t_{min} in left, which also means end of life

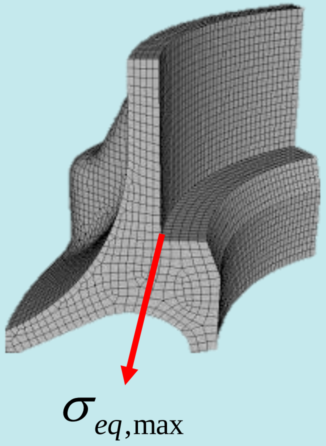
Operation stage



- During its life in services the thickness could somehow be corroded and becomes thinner.
- Suppose many years later when we are reaching this point.
- And this is the latest scheduled inspection. from the rate corrosion the thickness is expected to fall below t_{min}, which means end of life.
- The pressure vessel could leak or break before next inspection.

- If we wish the equipment can late till this date
- Operating' conditions must be adjusted

Theoretically Method



$$\sigma_{eq,\max} \leq \sigma_y \Rightarrow healthy$$

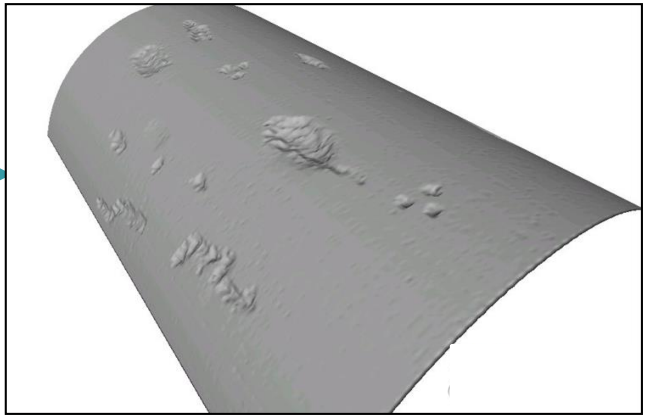
- Is there a thing that can respondent strength of the equipment …?
  Remaining Strength Factor
  1=New, perfect strength fresh at day 1
  0.9= lowest allowable strength, RSFa
- For equipment to be acceptable for continued operation
  RSF≧RSFa

RSF is needed for assessing equipment with defect

- The process for doing this is called Fitness for Service
  This study is based on "**API 579-1/ASME-1 FFS**"

Type of Defects

1. GML
2. LTA
3. Pitting
4. Dent
5. Gouge
6. …



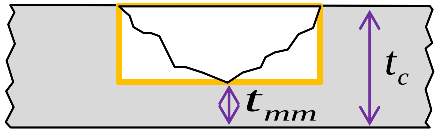
Ref：http://www.autsolutions.net/ProScan.html

FFS is a method for engineers and expert to assess whether the equipment with defects is acceptable.

➔ simple, practical, and accurate

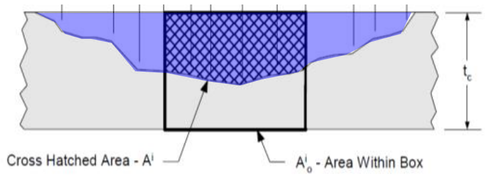
➔ The analysis can be divided into 3 levels

Level 1

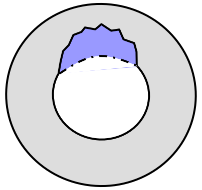


On rectangular defect profiles

Level 2



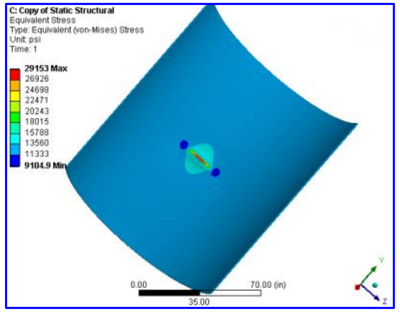
longitudinal local metal loss



circumferential local metal loss

On rearranged defect profiles

Level 3

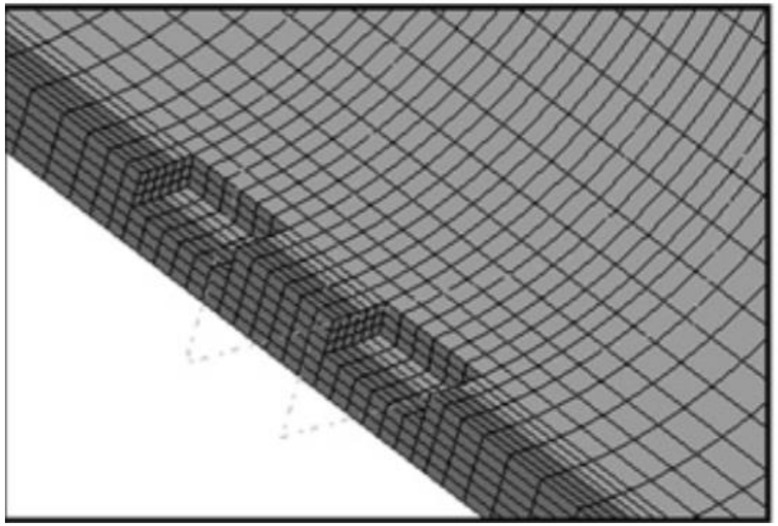


On actual defect Profile

1. L1 and L2 have limitations in use, so some situations still have to conduct by L3.
2. But there is currently no standardized implementation of L3.
3. In the FFS article, the FEM method is recommended.

Prior study : LTA analysis by FEM

1. Most studies found LTA difficult to use the actual profile and rather settle with a simplified profile, some with a parabolic shape and some with a rectangular cut-out. (Lee, G. H. et al.,2015., Jin-Weon Kim, 2008., Tan, W., Zhang, J. et al., 2012., Peng, J. et al., 2011., Duan, Z. X., & Shen, S. M., 2006., Xu, L. Y., & Cheng, Y. F., 2012., Hui, H., & Li, P., 2010., Tahara, T, 2003.)
2. A simplified finite element model with the LTA modeled as a symmetric shape and perform stress analysis on half or a quarter of the model, while some on a simplified 2D model, all for the purpose of saving computing time.(Lee, Geon Ho, et al. 2015) 、(Peng, Jian, et al., 2011) 、(Duan, Zhi-Xiang et al., 2006) (Bao, S. et al., 2019.



(Ref：Safety assessment of pipes with multiple local wall thinning defects under pressure and bending moment.,2011)

⬇

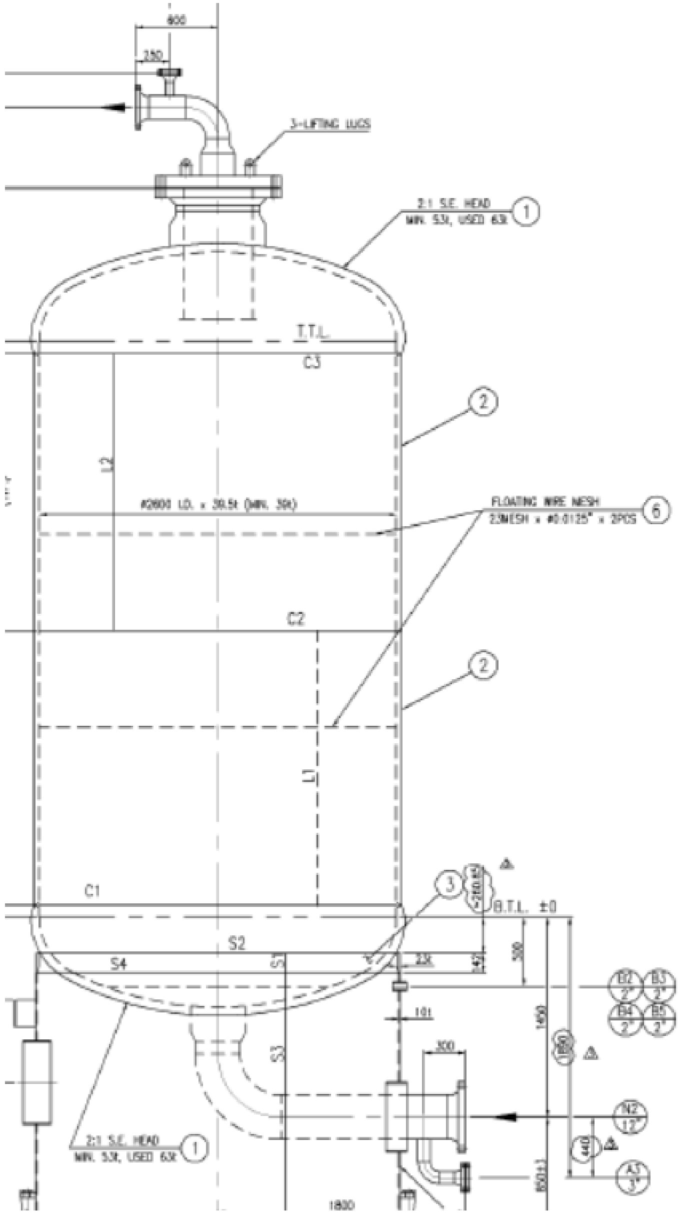
The fact is that the LTA is not regular, symmetric, and the weakest spot is located somewhere within the LTA.

⬇

The LTA model should not be replaced with any sort of simplified shape when used in assessing the remaining strength.

We aim is to develop **a standardized Level 3 method** that meets the API 579 evaluation criteria based on FEM to more accurately measure the remaining strength of the LTA.

Experimental object description(1/4)-equipment



main model		
parameter	Unit	
Nominal thickness	*mm*	31.75
Inner diameter	*mm*	762
Equipment high	*mm*	6096
t_{min}	*mm*	25.40
Design Pressure	*MPa*	3.93
Design Temperature	^oC	343
Material specification		SA-516 Grade 70

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Experimental object description(2/4)-defect

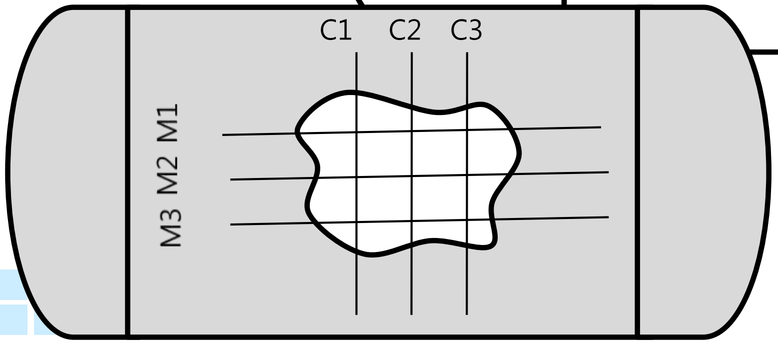
31.75mm

31.75mm

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C_CTP
M1	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21
M2	29.21	25.40	25.91	26.67	24.89	25.40	24.64	24.13	24.64	25.40	29.21	24.13
M3	29.21	24.64	24.89	23.37	22.86	23.37	24.13	23.37	24.13	24.38	29.21	22.86
M4	29.21	25.40	24.13	22.10	22.10	22.61	23.62	22.86	23.37	25.40	29.21	22.1
M5	29.21	24.38	23.62	21.59	21.84	21.84	22.86	22.10	22.86	24.38	29.21	21.59
M6	29.21	25.91	23.37	21.34	22.10	22.35	21.08	22.61	23.37	25.91	29.21	21.08
M7	29.21	24.89	23.88	21.84	22.61	22.10	21.59	22.86	22.86	24.89	29.21	21.59
M8	29.21	25.40	24.13	23.88	21.84	22.61	23.37	23.88	23.37	25.40	29.21	21.84
M9	29.21	24.38	23.37	23.37	22.10	23.37	24.64	22.86	24.13	24.38	29.21	22.1
M10	29.21	25.40	24.64	24.13	23.37	24.89	25.40	26.67	25.40	25.40	29.21	23.37
M11	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21	29.21
L_CTP	29.21	24.38	23.37	21.34	21.84	21.84	21.08	22.1	22.86	24.38	29.21	(*in*)

C=317.5mm

S=317.5mm

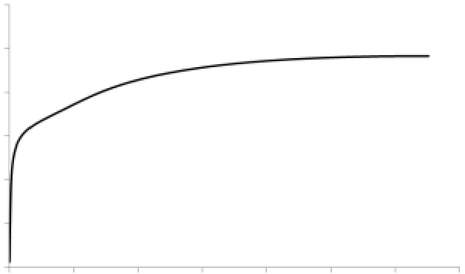


1. A defect from the equipment by NDE.
2. We used a grid method to obtain a detailed thickness distribution of defect.
3. Longitudinally and circumferentially measure 11 points, and the spacing is 31.75 mm.
4. This defect is a square defect,

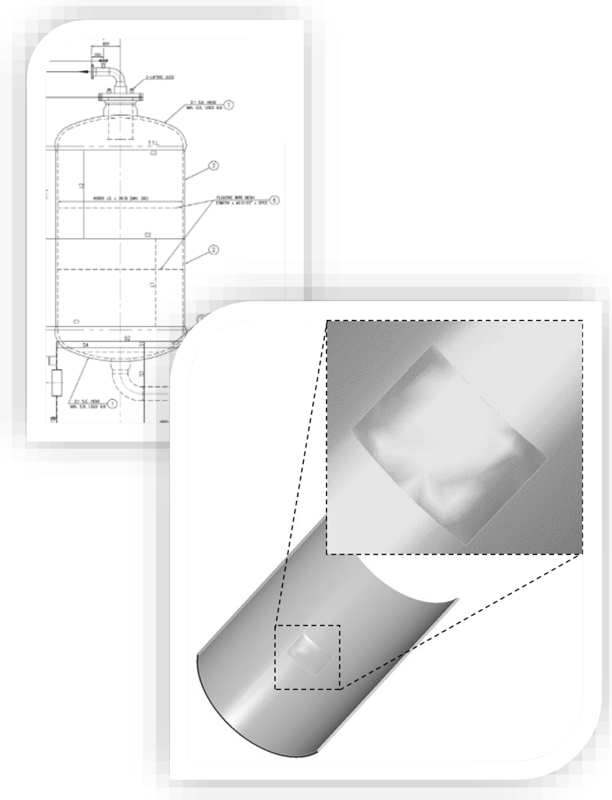
$$RSF = \frac{L_{DC}}{L_{UC}}$$

Plastic collapse load (PCL)

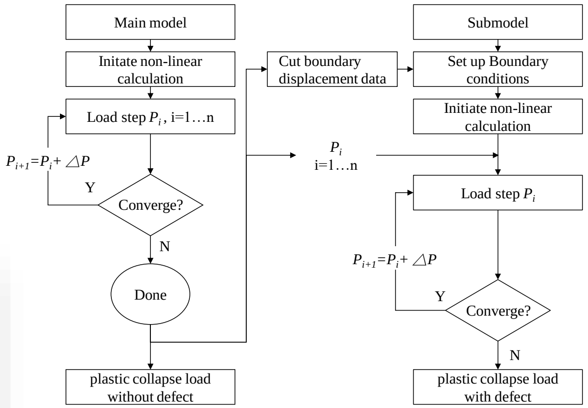
Material stress strain curve



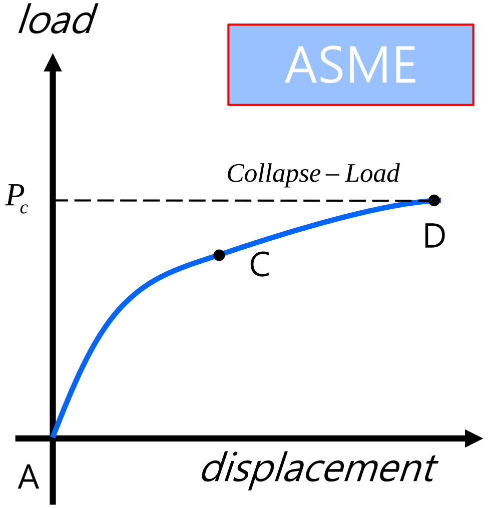
Geometry



Analysis



Load displacement curve

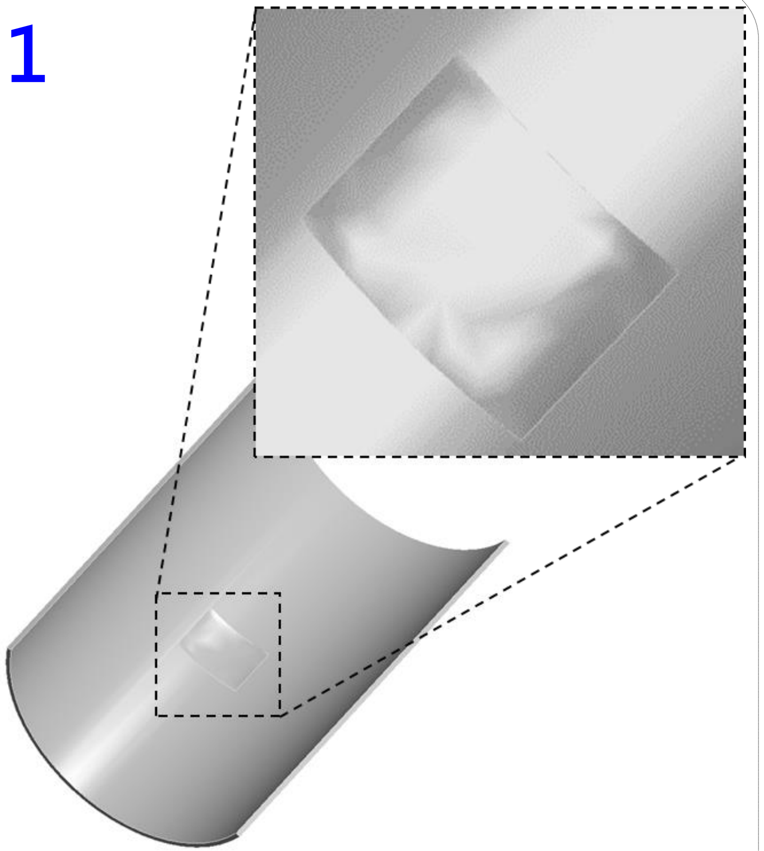


The step of RSF by FEM:

① Material model establishment
② Geometric model
③ Analysis
④ Drawing load displacement curve and definition of PCL

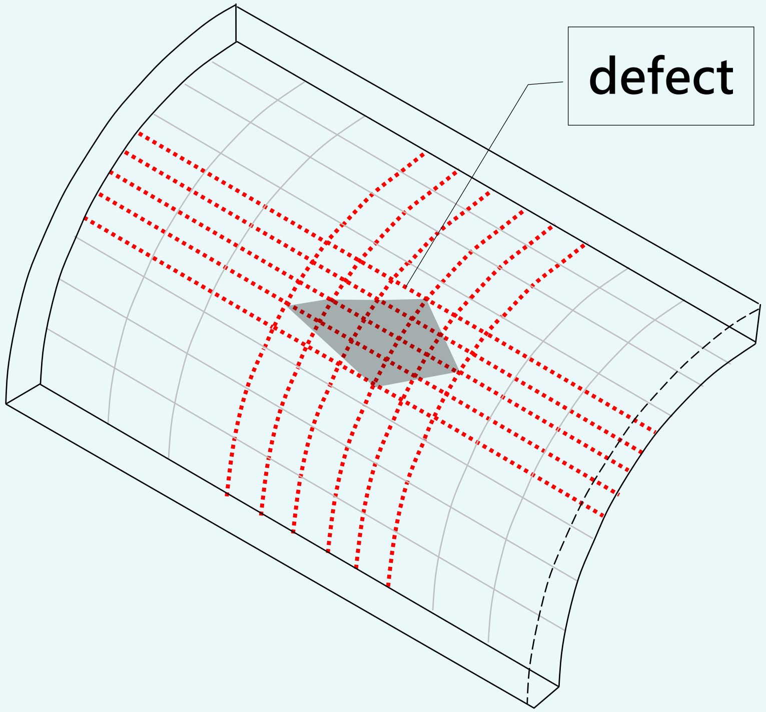
2.Defect submodel

1

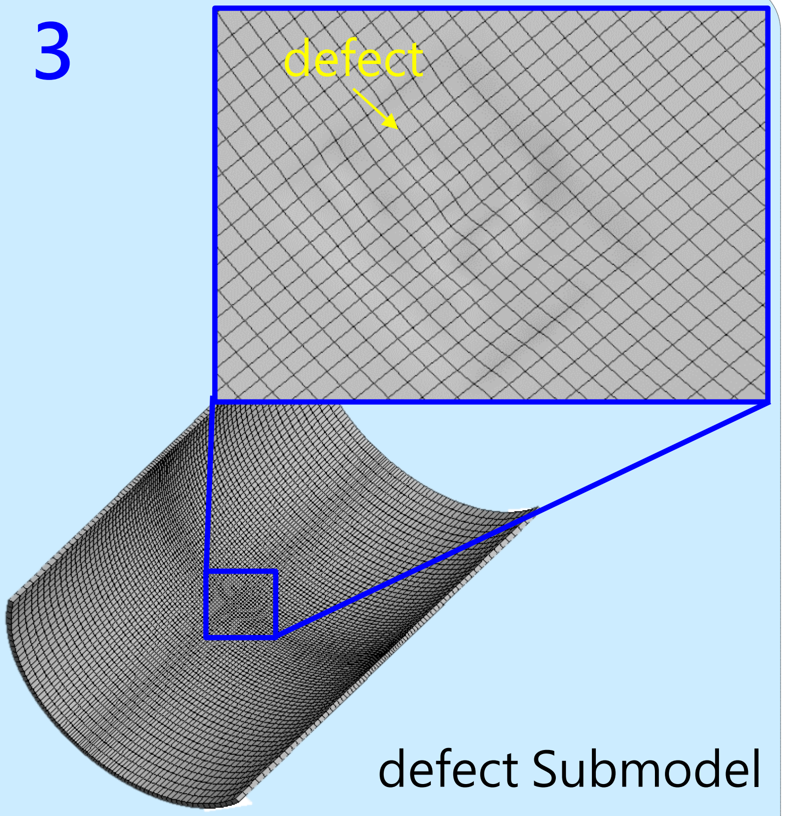


We build the LTA model.

2



3

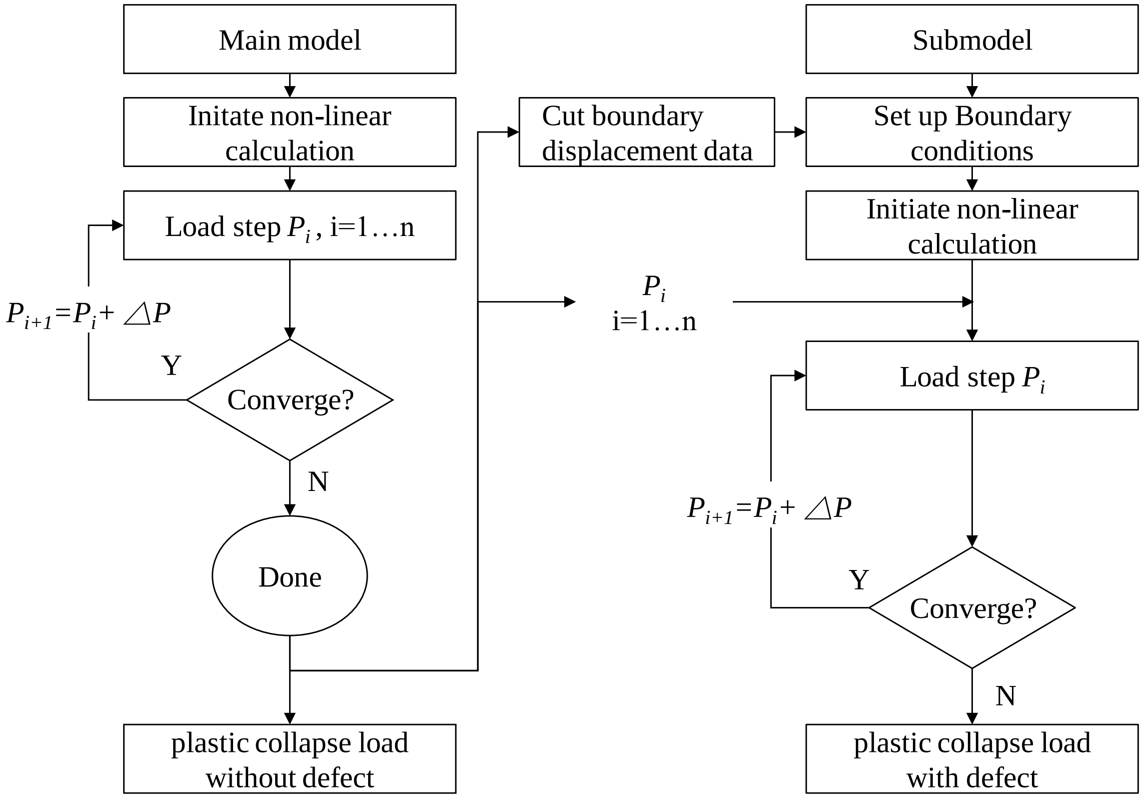


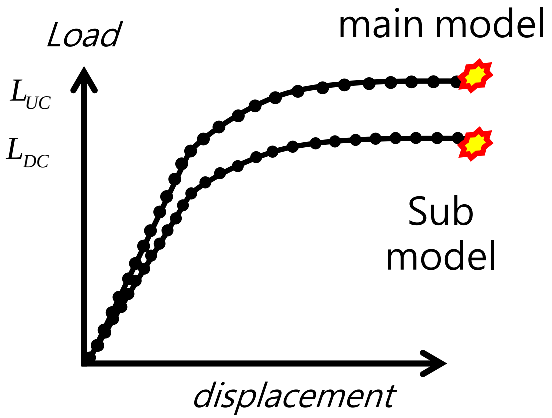
Number of gridding elements :14,400

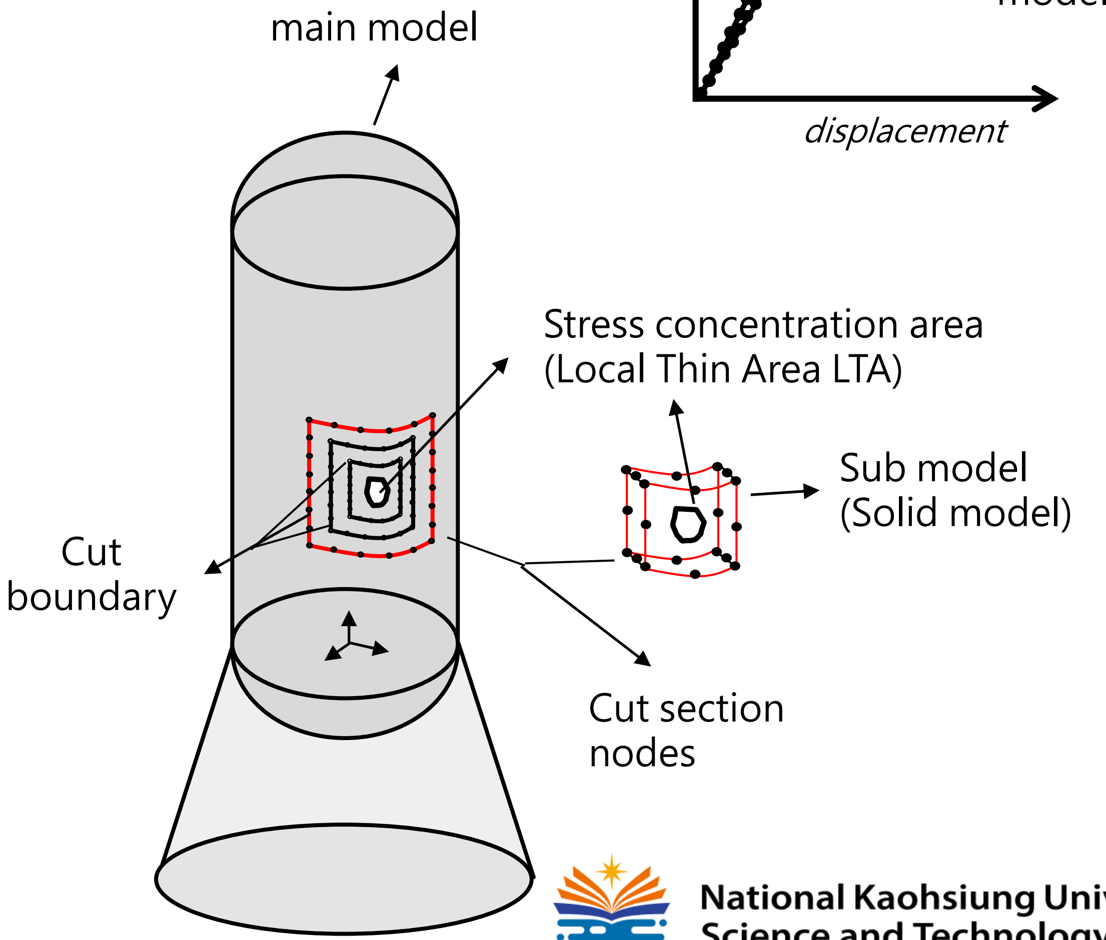
Grid quality :

- Orthogonal quality(1~0) : 0.999
- Skewness quality(0~1) : 0.0240

3.Analysis-PCL & 4. RSF



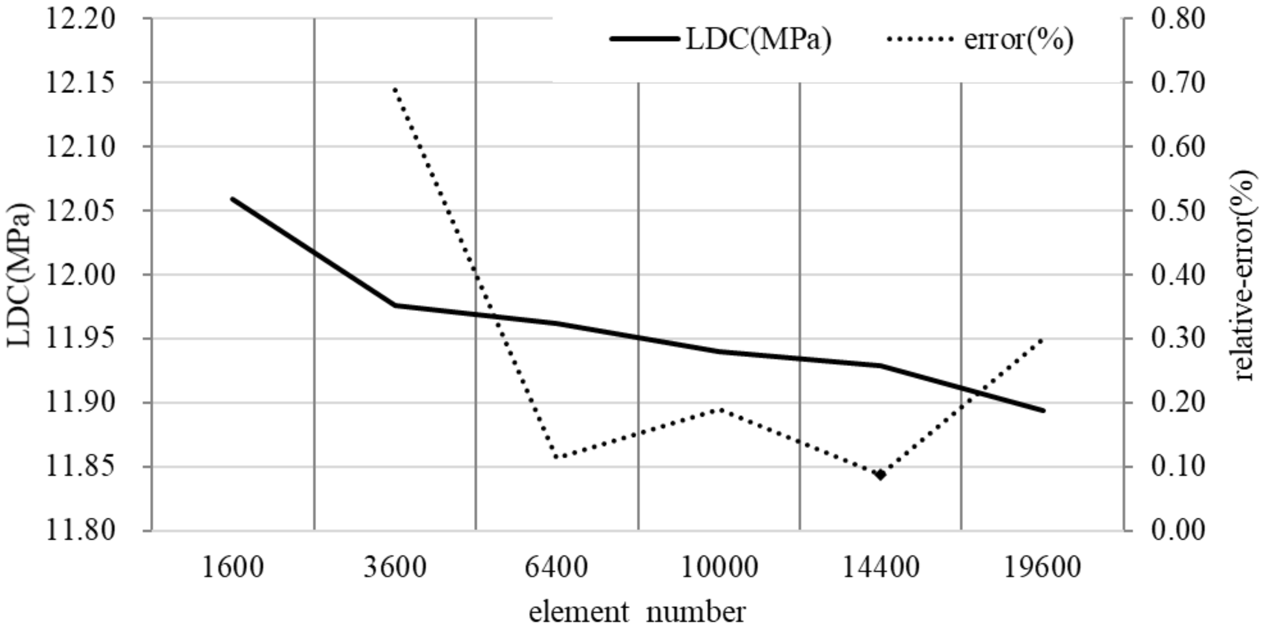




1. The load iterate on the main model
2. The submodel will begin at each load step with displacement values at the cutting boundary passing from the main model to the submodel.

Result

- To ensure the convergence of numerical analysis, a relative error method is used herein to make sure the element size is proper, and the result of PCL converges.

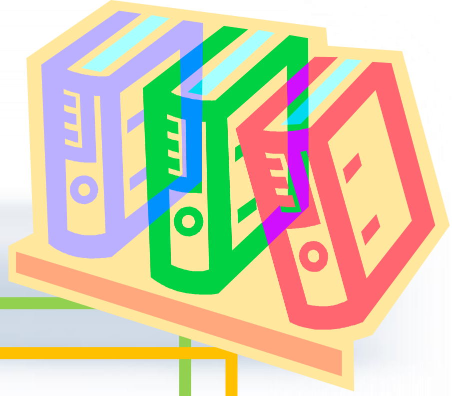


- the 14,400 elements model is selected to use throughout the whole study.

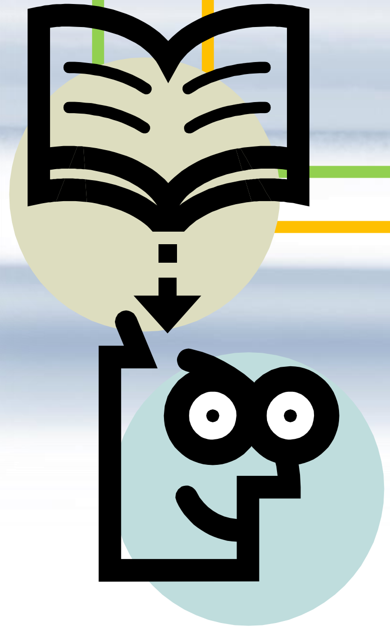
	Main model	defect submodel
Collapse load (MPa)	13.2379	11.9279
RSF	1.000	0.901

Conclusion

- This study **develop a standardized Level-3 method** that complies with API 579 evaluation criteria. It is an analytical method without any simplification so that the true remaining strength of the structure can be obtained.
- There are several **important results** obtained herein.
  1. The rendering method of real LTA is proposed.
  2. Submodel analysis of LTA is performed.
  3. PCL calculation procedure of a defect is proposed.



THANKS FOR YOUR ATTENTION~



Presenter：Yen-Ju Lu
Advisor：Prof. Chen-hua Wang
0515912@nkust.edu.tw
cwang@nkust.edu.tw
National Kaohsiung University of Science and Technology