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Scientific Notebook No. 415: Repository Design and Thermal-Mechanical Effects (07/30/2000 through 10/09/2000)

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

CNWRA
CONTROLLED
COPY 415

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Repository Design and Thermal-Mechanical Effects (RDTME)

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This notebook documents the work being done to develop conceptual models including process-level WP analysis and rockfall study for upgrading the SEISMO module to be included in the future version of the TPA code. See the Operations Plan for Repository Design and Thermal-Mechanical Effects for more details.

The qualifications required of the staff supporting this endeavor are as follows:

a) Computational Continuum Mechanics/Finite Element Analysis
b) Material Science/Metallurgy
c) Rock Mechanics
d) Civil and Mechanical Engineering
e) Geological Science and Engineering

Doug Gute 8/4/2000

Jul. 30. 2000 *07:00 AM ~ 11:00 PM (Sun.)

Travel from State College to San Antonio 기내에서.

Jul. 31. 2000 05:00 ~ 06:00PM (Mon.) at CNWRL

meeting with Dr. Gute

◎ Modeling of Container

○ Welding lids → residual stresses

⇒ calculated by using axisymmetric structural elements (as shown in ANL-EBS-MD-000006 REV00 titled 'Stress Corrosion Cracking of the Drip Shields, the Waste Package Outer Barrier, and the Stainless Steel Structural Material')

· The analysis results may contain errors of 5~10% itself. Though the results are effective, axisymmetric models can hardly represent rockfall effects. That's the reason to reconstruct three-dimensional analytical model which contains the concept of heat transfer.

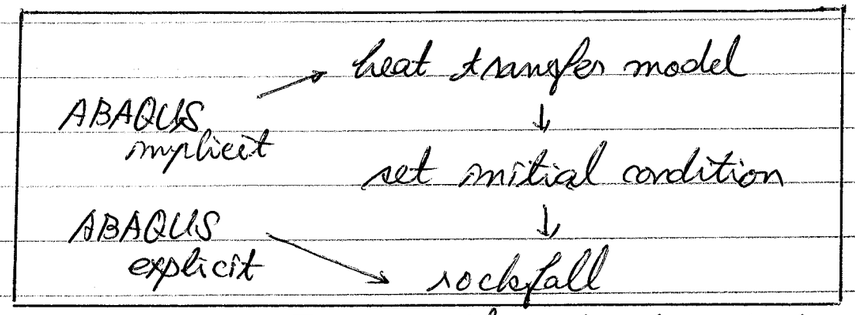
· In those analysis the representative parameter is welding travel time to weld entire circumference and affecting environmental temperature in the view of heat transfer.

· The second consideration in reconstructing analytical model is rockfall analysis regards residual stresses resulted by heat transfer analysis to initial conditions. In this state of analysis, as shown in report produced in Penn State ("Rock Impact Effects on the 21-PWR Nuclear Fuel Storage Container" by T. Krauthammer, J. Kim and G.J. Oh) rock size, rock shape, falling height,

and attack position would be considered as parameters.

· The third point of consideration is structural boundary conditions. In previous analysis the boundary condition of structural system is assumed as a fixed boundary condition in the position of pedestal. In this analysis, however, to precise the accuracy of analytical result contact surface boundary condition should be adopted to simulate more realistic physical conditions.

· Considering above three analytical fact, the strategy to reconstruct analytical model is abstracted like below.



<Fig 1.> model construction strategy (he explained by Dr. Gute)

기내에서 Jul. 31. 2000

Aug. 1. 2000 01:00 AM ~ 06:00 PM (Tue) at CNWRL

◎ Examining report titled 'Stress Corrosion Cracking of the Drip Shields, the Waste Package Outer Barrier and the Stainless Steel Structural Model'; Document identifier ANL-EBS-MD-000006 REV00. approved at April. 17. 2000. (especially welding analysis.)

- Used model
  - Stress Corrosion Cracking (SCC) threshold model
  - SCC slip dissolution/film rupture model for Alloy 22
- Inputs
  - material parameters
    - for thermal analysis:
      - thermal conductivity (k)
      - specific heat (c)
      - density (ρ)
    - for stress analysis
      - coefficient of thermal expansion (α)
      - Young's modulus (E)
      - poisson's ratio (ν)
      - density (ρ)
      - yield stress (S_y)
  - welding parameters
    - The net heat input (H_{net}) can be calculated according to eqn (2-3) of DTN: LL000312705924.132 for given parameters and is like as shown,

$$\text{welding heat input} = \frac{\text{heat transfer efficiency} \times \text{voltage} \times \text{amparage}}{\text{travel velocity}}$$

or $$H_{net} = \frac{f_1 E I}{v}$$

and its dimensions are represented as,

$$(\text{joul/in.}) = \frac{(V)(A)}{(\text{in} \cdot \text{in/sec})}$$

- The lids of WP are welded with the (NG-GTAW) (Narrow Groove Gas Tungsten Arc Welding) Parameters for that type of welding is defined in CRWMS M&O (civilian radioactive waste management system, management and operating contractor) and DTN: LL000312705924.132

$I = 330 \sim 335\ A$

$E = 12.1 \sim 13\ V$

$v = 8.0$ in in/min

$f = 21 \sim 48\%$

- threshold stress intensity factor

$(K_{ISCC})_M = 30\ ksi(in)^{\frac{1}{2}} = 33\ MPa(m)^{\frac{1}{2}}$

$(K_{ISCC})_\sigma = 1.61\ ksi(in)^{\frac{1}{2}} = 1.77\ MPa(m)^{\frac{1}{2}}$) test result

assumed threshold range,

$(K_{ISCC})_M - 4 \times (K_{ISCC})_\sigma \le K_{ISCC} \le (K_{ISCC})_M + 4 \times (K_{ISCC})_\sigma$

in slip dissolution model

$A = 1.8 \times 10^{-3}\, n^{3.6}$

- Analytical assumption
  - DS is excluded from SCC evaluation
  - 316NG stainless steel inner barrier is excluded from SCC, too.
  - $S_m - 2t \sim 30\%$ of $S_m < S_y < S_m + 2t \sim 30\%$ of S_m
  - embedded flaws will not grow due to lack of cyclic stresses
- material property
  - $k = 10.1\ W/(mK)$ at $118°F$

    $c = 414\ J/(Kg\,K)$ at $126°F$

$\rho = 8690$ kg/m at 24°C
$\alpha = 12.4 \times 10^{-6}$ m/(mK) at 76°F
$E = 206$ GPa at 76°F
$\nu = 0.278$
$\rho = 8690$ kg/m at 24°C
$S_y = 372$ MPa (54 ksi) at 24°C

- H_{net} varies with velocity (v)
  → total heat input in axisymmetric model is $L \times H_{net}$
  where L is circumference length of lid
  기재하시오 Doug Ste 10/2/2000

Aug. 2. 2000 07:00am ~ 06:00pm (Wed) at CNWRL

◎ Problem Definition (first trial)

standard analysis
parameters defined CRWMS M&O
I, E, f
$k, c, \rho, \alpha, E, \nu, S_y$
↔ parameters (mainly v)

↓ stress intensity factor ↔ compare with axisymmetric analysis

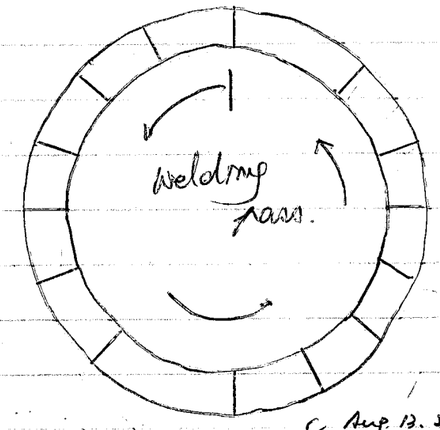
set initial condition

↓

explicit analysis
rock shape
rock size
drop height
attack point
← structural boundary conditions

→ resultant Von/Mises Strain Energy Density.
(Fig 2)

◎ Geometrical dimension of welding detail.
- meeting with Dr. Gute.



C Aug. 13. 2000

Fig 3. welding travel

* what kind of heat input was used for axisymmetric model?
· Two inputs could be used that is energy and temperature.
· It is shown in the reference of ANL-EBS-MD-000005 REV00 (Stress Corrosion Cracking of the Drip Shields, the Waste Package Outer Barrier, and the Stainless Steel Structural Material) April. 2000, pp ~10~10.

The net heat input (H_{net} in Joules/in.) can be calculated according to Eqn. (2.3) of DTN: LL000312705924.132 for given welding parameters including Voltage (E), amperage (I) travel velocity of heat source (v in in/sec) and heat transfer efficiency (f_1), i.e., $H_{net} = f_1 EI/v$. The WP lids will be welded with the Narrow Groove Gas Tungsten Arc Welding (NG-GTAW) process utilizing hot wire feed (CRWMS M&O 1998, p. 11) For this type of welding process the amperage, voltage, and average travel speed are, respectively, 330-335 A, 12.1~13.0 V and 8.0 in./min. (CRWMS M&O 1998, Table 7-1 p. 12) According to DTN: LL000312705924.132, the heat

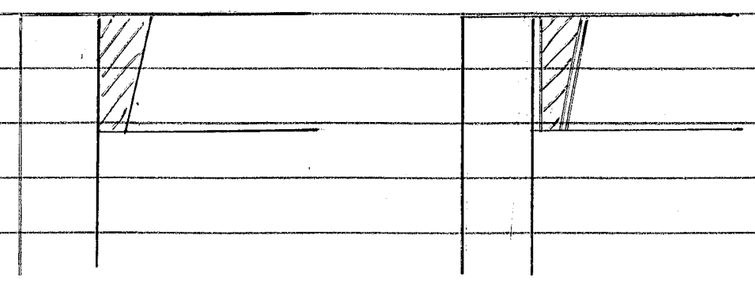
C 9 Aug 13. 2000

transfer efficiency for gas tungsten arc welding is 2/~ 48%. ↓

* Referring to those contents, the unit of heat input is Joul/in.
  - And p 34 of same material.

⊢ The induction heat annealing process to be applied to the WP includes rapid local weld heat up at about 1000 to 1120°C for short hold time (about one minute) followed by rapid cool down to < 600°C in about 10 minutes.) ↓

- As shown above sentence the heat input used in this case is Energy in the unit of 'Joul/in.'
- From the equation $H_{total} = L H_{net}$, H_{net} was calculated as a form of heat energy per length.
- In construction of 3D model, heat should be applied heat energy per area or per volume.



(a) heat input per volume (b) heat input per area

Fig. 4 Heat applied to 3D model.

- Namely, the unit would be Joul/in² or Joul/in³ and even W/volume.

⊙ Discretization of solid mesh.

- Problem of full solid mesh.
  - too much element
  ↓
  too much DOF
  ↙ can't analysis by present computer system
  ↘ can hardly analysis
  ↓
  can hardly examine resultant output

Fig 5. solid meshing problem

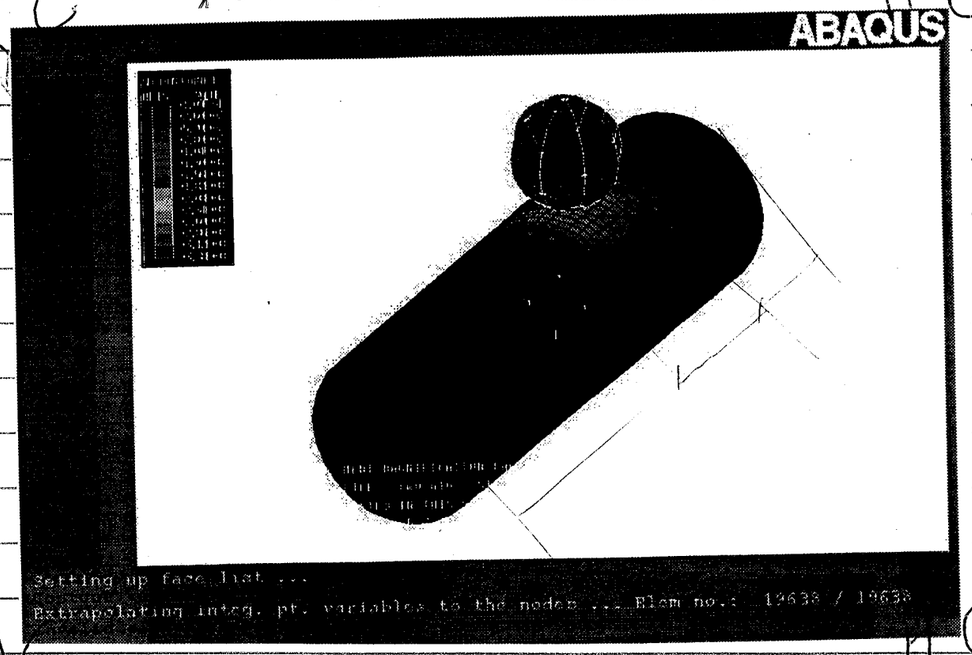
- Model should be composed of as small number of elements as possible.
- We can reduce model DOF by using mixed element model of solid elements and shell elements.
- In that model, interested zone should be modeled by solid model to examine 3D stresses like Von Mises failure stress
- As shown in Fig 3., the fundamental aim of this analysis is rockfall analysis whose initial condition is residual stresses by heat input produced during welding.

  So, the reduction of DOF in 3D model should be considered in the view of two analysis results as shown.

  ① residual stress affecting zone by welding
  ② impact stress affecting zone by rockfall

- In general, the nature of heat transfer, the residual stress affecting zone is set very close. DA 10/2/2000
- So the radial model area or region could be determined by rockfall analysis region.
- From the past report which contains rockfall simulation named 'Rock Impact Effects on the 21-PWR Nuclear Fuel Storage Container', we can deduce the affecting region by rockfall.
- We can examine two cases of simulation results as,
  1. spherical rock impact over a support and top of the container
  2. spherical rock impact over an edge and top of the container

Aug 14 2000



Aug 14 2000

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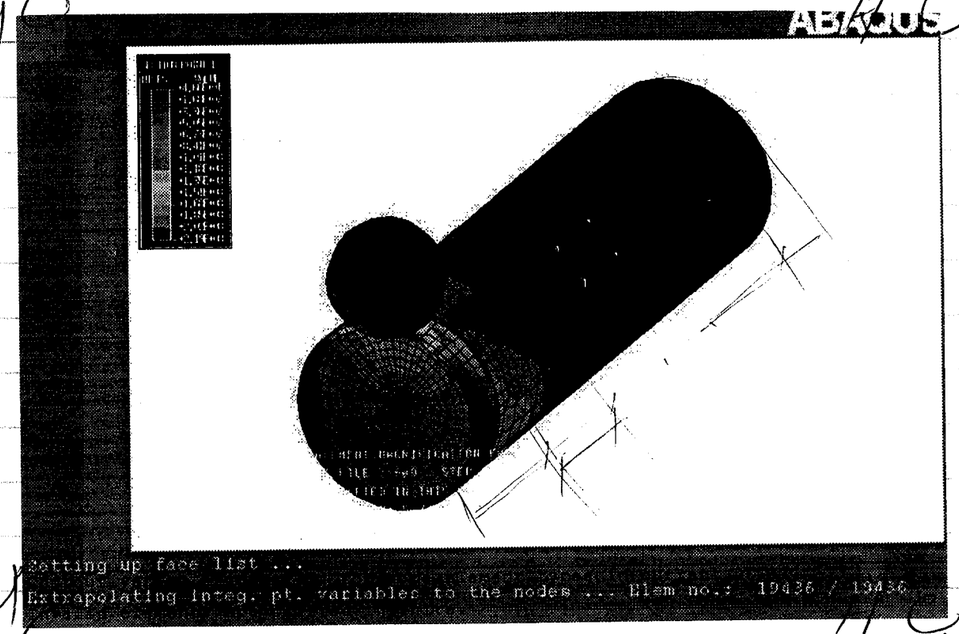
Fig 6 stress result contour plot of spherical rock impact over a support.

Aug 14 2000



Aug 14 2000

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Fig. 7 stress result contour plot of spherical rock impact over an edge.

- We can refer the stress result of directly on Fig 7 or even we can examine Fig. 6.
- As shown above two figures, stresses due to rockfall affects within the range of 25% from rockfall impact edge. Therefore we can assume that the affecting range from edge to 1/4 L (L : barrier length)
- That is to say, we can construct model as below,
  1. from welding edge to 1/4 L : solid element
  2. from 1/4 L to the end : shell element with coarse mesh.
  3. link between solid element and shell element.

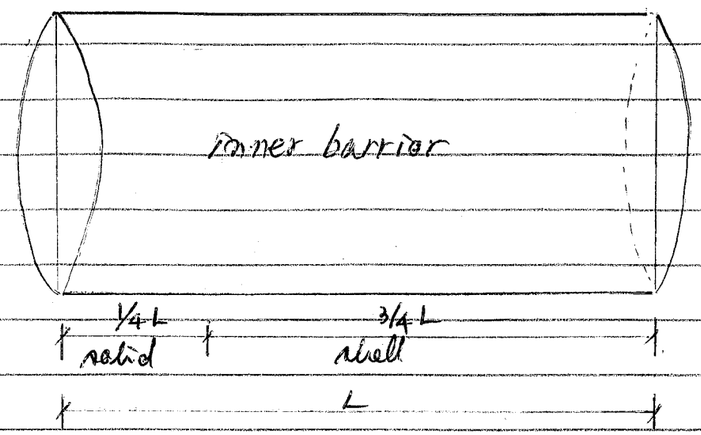


Fig. 8. model definition (element)

- Element connection
  Cross-section of 1/4 L which is border of solid element and shell elements are connected by MP of ABAQUS which is a kind of 6 rigid link. (Fig. 9)

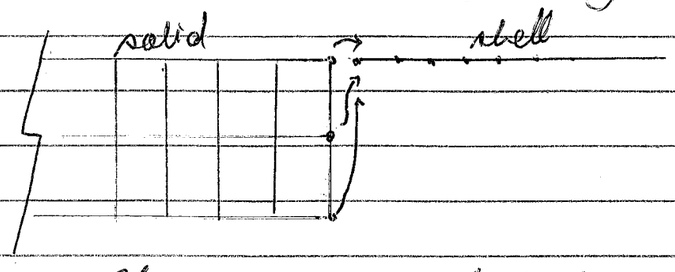


Fig. 9. connection of border.

In real construction, the gap between inner barrier and outer barrier is ignored, but as shown in Fig. 10, there are some different behavior between

shear free surface and shear locked surface.

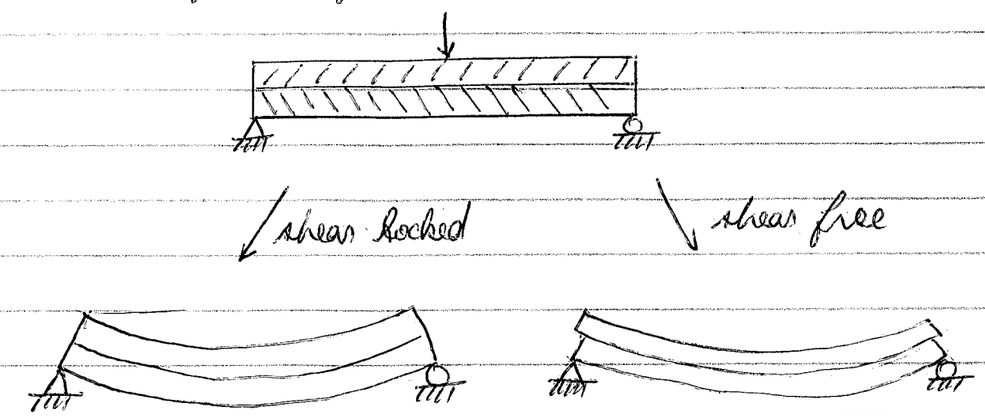
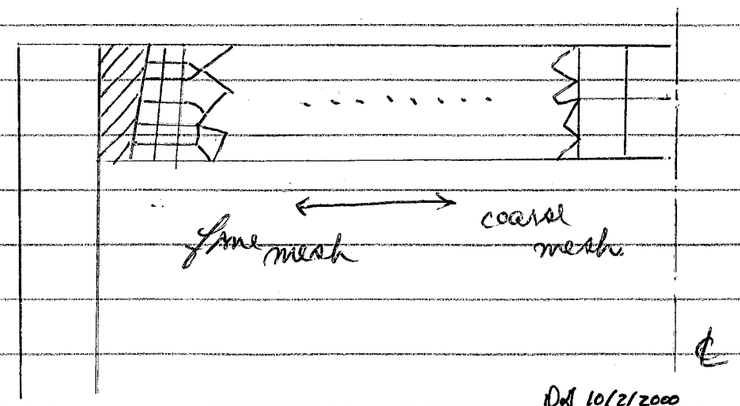


Fig 10. shear locked surface and shear free surface

To simulate, in this case, shear free (friction free) surface, the model should contain gap between inner and outer barrier as an initial (force free) condition. And for the same object, the shell element of inner barrier should be placed outer node of solid cross-section, and also, the shell element of outer barrier should be placed inner node of solid cross-section. The problem of neutral axis of cross-section which is produced by such a placement of shell elements are overcomed by offset setting.
By rigid link element MP and gap condition and offset setting could make the modeled structure behavior continuously. Such as connection, shear free surface as a initial state, and the problem of neutral axis, relatively. (Fig. 11)

- One more trial could be applied to reduce DOF of model structural.
- Since we are to know the stress intensities of local region around welding passes, fine and coarse mesh control would applied shown Fig 11.



Dot 10/2/2000

Fig. 11. fine and coarse mixed model.

- Generally, in those models, the bad aspect ratio problem revealed, in this analysis, however, it could be ignorable for the aim of analysis.

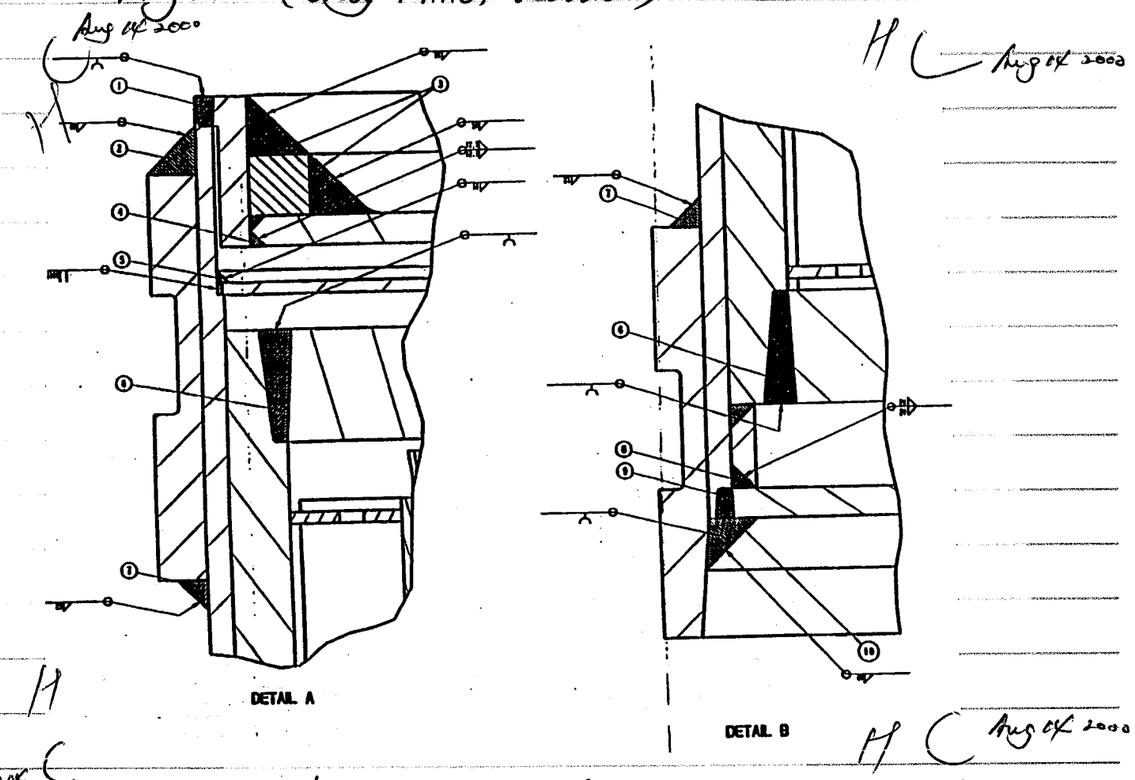
Doug Sato 10/2/2000

Aug. 3, 2000 01:00 ~ 18:00 (Thu.) at CNWRL

⑨ Detail model definition (welding)

<referring to ANL-XQS-ME-00000 / REV 00 named; Design Analysis for the Ex-container Components>

- upper and lower barries dimensions are shown in Fig. 12. (only inner barrier)



Aug 14 2000

Fig. 12. Lid welding detail (A) and factory made welding detail (B)

Modeling starts from inner barrier and to clarify direction cosine, axis direction of structure is defined as shown in Fig 13.

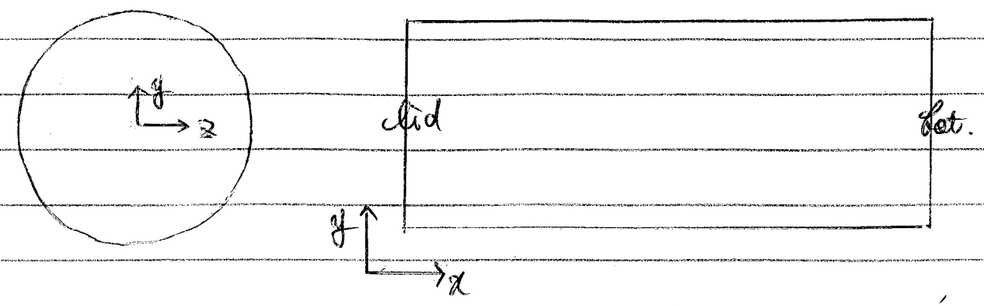


Fig. 13. Model axis direction definition of inner barrier

By the drawing SK-0175 REV 02 of ANL-XCS-ME-000001 REV00 the simplification of welding area, inner lid and inner barrier is as shown Fig. 14

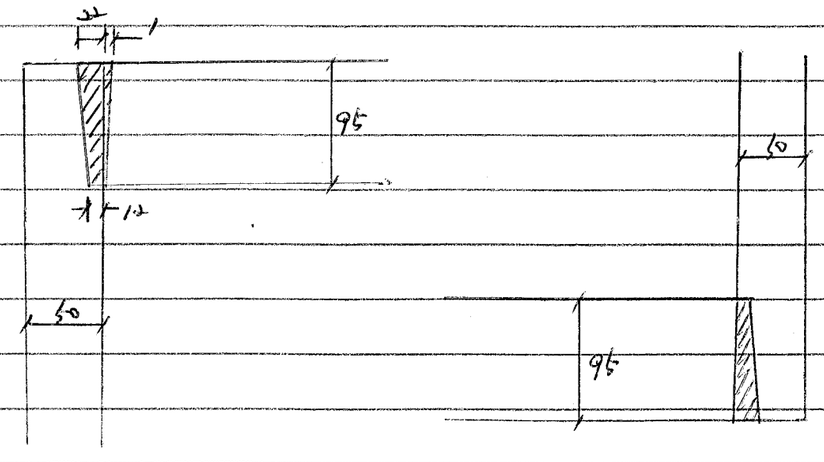


Fig 14. Structure simplification for analytical model.

DS 10/2/2000

And ~~stiff~~ referring to same material the global structural cross-section model is as shown in Fig. 15.

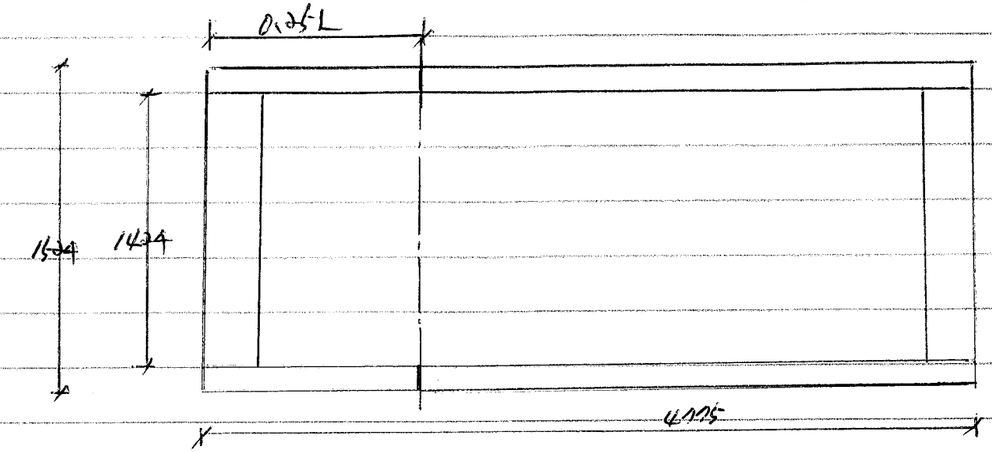


Fig. 15. global structure shape.

To construct analytical model by using Hypermesh, seperate element sets as below.

① IBS (inner barrier solid)
② ILS (inner lid solid)
③ IWS (inner weld solid)
④ ISHB (inner barrier shell)
⑤ ISHL (inner lid shell)

To make IBS first assumed cross-section(half) is as shown in Fig. 16

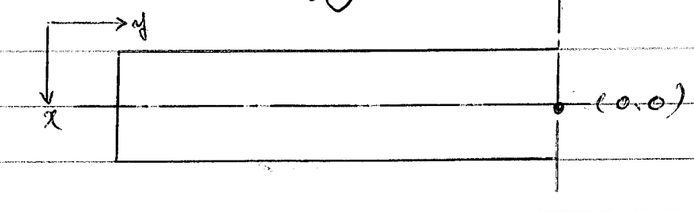
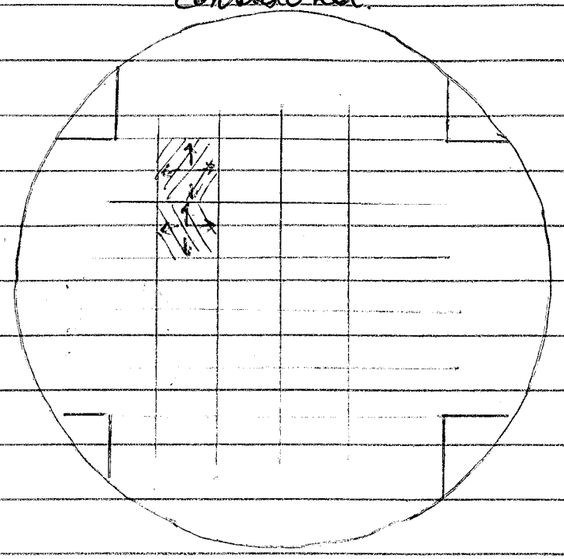


Fig. 16 half cross-section for inner lid solid

◎ meeting with Dr. Gute.

① temparature of inner fuel storage should be considered.



in analytical model, inner storage seperation could be modeled as shell elements and fuel capsule could be modeled by mass ~~beam~~ only beam element. 10/2/2000

Fig. 17. inner fuel storage.

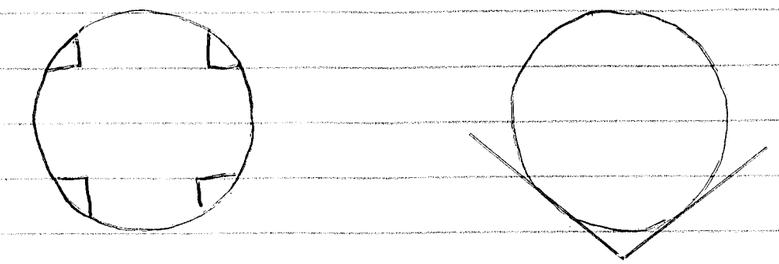
To make heat input, we can use relations like below,

$$\frac{Q}{Vol.} = SNF \rightarrow \text{Watts generated}$$

$$\frac{\frac{Q}{Vol.} \cdot Vol}{SA \cdot cell} \Rightarrow \text{fixed heat flux}$$

in the model considered inner fuel temparature, the main parameter is relations between environmental temparature and fuel temparature.

◦ boundary condition definition



(a) (b)

Fig. 18 boundary condition of inner cell (a) and outer barrier (b).

Boundary condition of inner cell is regarded as inner barrier. and the outer barrier is placed on the V shape frame without any fixed connection. (only contact condition)

◦ Matrix reduction (suggested by Dr. Choi).

To reduce structural DOF, matrix reduction technique could be introduced.

→ could be tried after direct analysis (Dr. Gute)

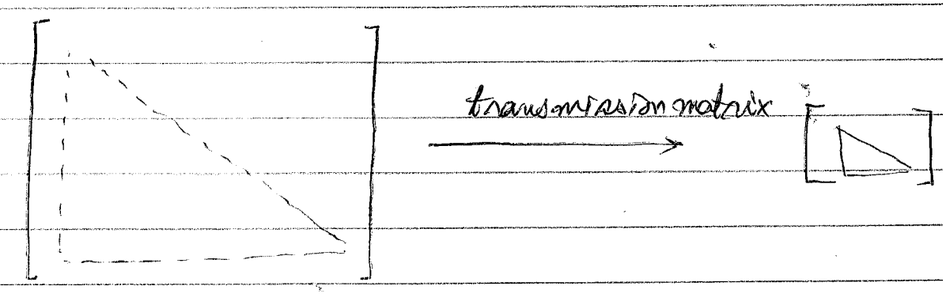


Fig. 19. Matrix Reduction Technique.

◎ Modeling Procedure (by using Hypermesh).
To construct solid model of inner lid, we can make 2D-Quad rectangular model.

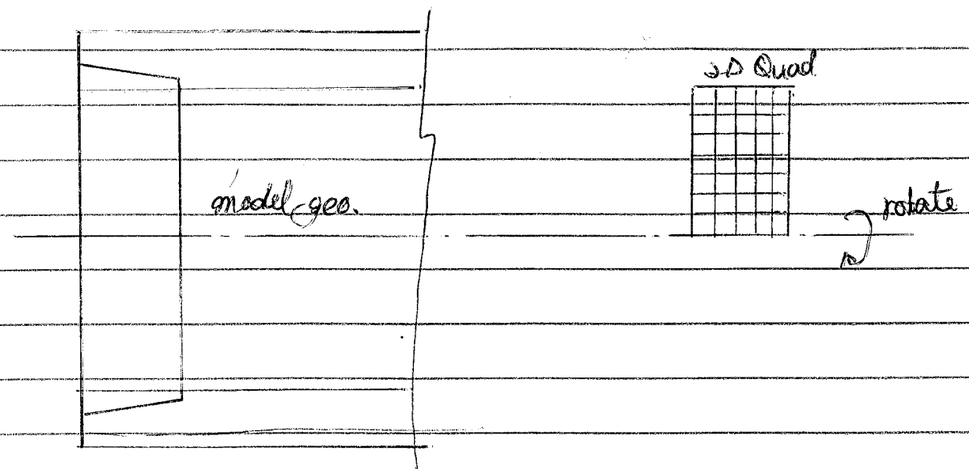


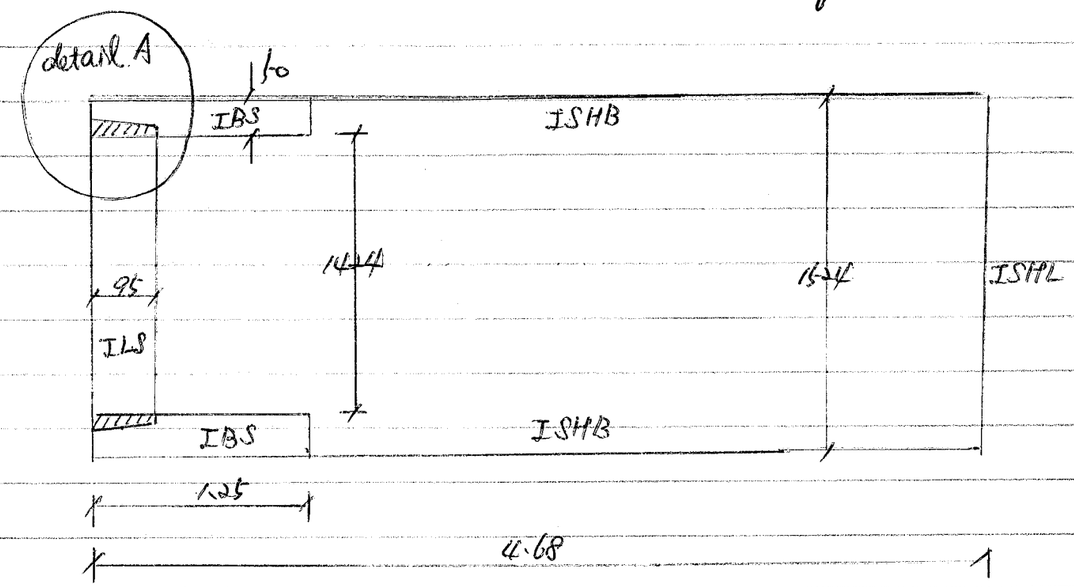
Fig. 20. 2D quad model

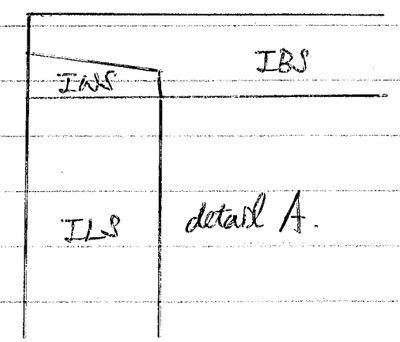
- In 2D Quad model, to make more efficiency in the view of aspect ratio to node with 1t bias is appropriate.
  * Because the input of numbers was typed in the unit of meter, too small numbers are inputed to exceed numerical tolerance, so hypermesh option should be changed like as.

  node tol 1.0×10^{-4}
  clean up tol 1.0×10^{-6}
  geom tol 1.0×10^{-7}
- Direct element data base as,
  ABAQUS standard.3d
- control collectors.

- 3D Modeling method in Hypermesh.

  construct surface (2D Element) < rotate surface / drag surface *.
- cross-section definition (geometry) and member (element) section definition.

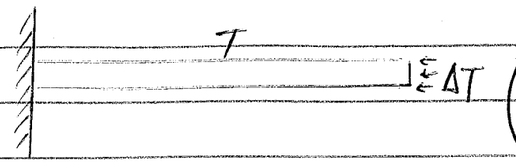




- normal surface of element must be checked for definition of contact surface

Fig 21. element section definition and model geometry.

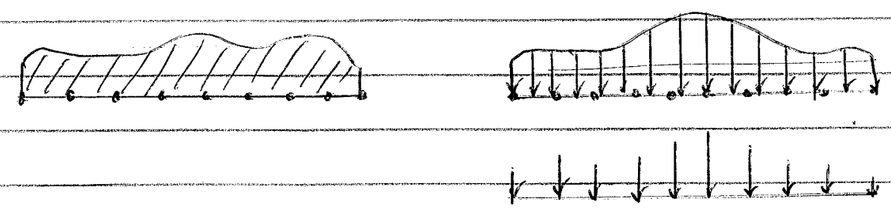
- Heat input type



(relation between
heat input ΔT
environmental thermal T.

Fig. 22 basic nodal heat input

- heat input is presented point(node), surface (2Delement) and volume in real state. As shown in Fig 23. when the heat input is subjected to line how can it be converted to nodal temparature like a distributed load.



(a) distributed heat (b) distributed load

Fig 23. conversion of heat and load

- In ABAQUS 5.7, the body flux and surface flux can be applied to the structure by command.

* DFLUX

It is not built in command but composed user subroutine command. (ABAQUS user's manual 19.4.3)

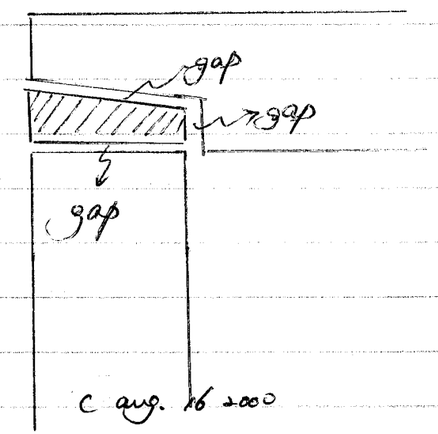
- In the report of ANL-EBS-MD-000005 REV00 (name: Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural material), the passing layer of welding is assumed to 6 passes.

And net heat input is found to be 1200 joul/m.

⇒ the total heat input of each complete welding pass is L (= 9.68 m) × H_{net}

$\frac{9.68}{\pi} = 3.05$ → two times of real diameter. (fault of report).

- Type of heat input.
  - when surface load is applied.



· infinitesimal gap between welding material and inner lid, and between welding material and inner barrier is needed

Fig. 24 heat input subjected to welding surface.

- when initial condition of heat on the whole welding volume is subjected.

⇒ It's more conservative with less assumption.

⇒ choosen.

Doug 10/2/2000

Aug. 4. 2000 01:00 ~ 18:00 (Fri) at CNWRL

◎ Model geometry and section model

- ILS (inner dia solid) model

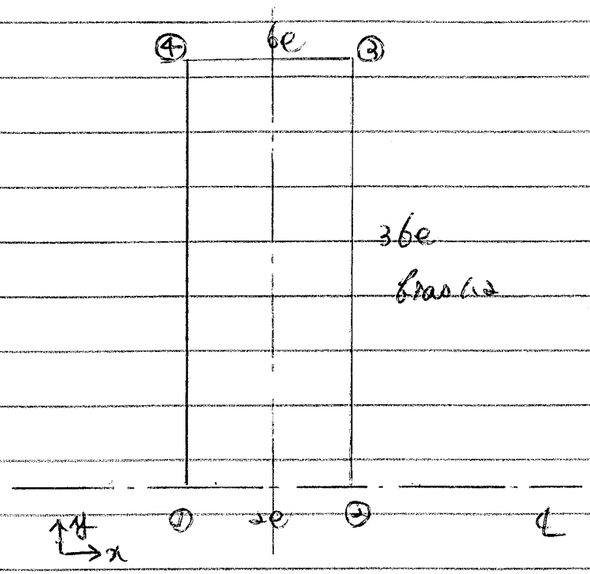


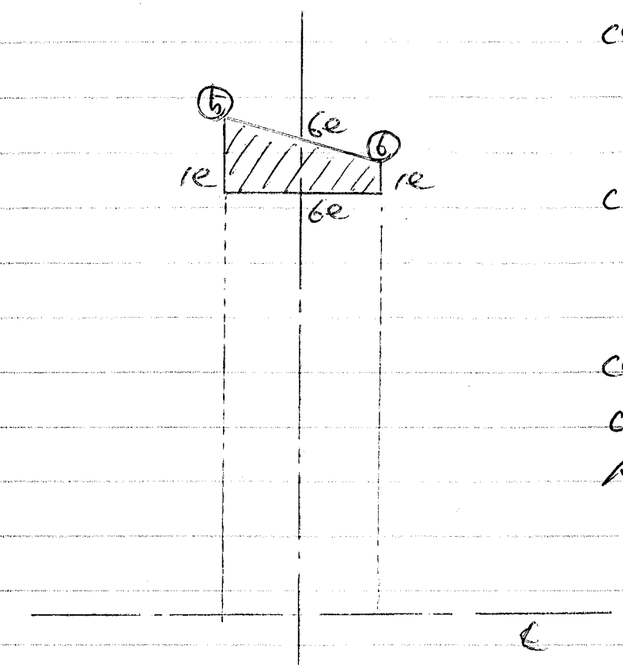
Fig. 2t ILS model
2D definition
(*'e' means ~~mine~~ no. of elements)
Aug 16 2000

global - ABAQUS.3D

- coordinate
  - ① (-0.0475, 0)
  - ② (0.0475, 0)
  - ③ (0.0475, 0.712)
  - ④ (-0.0475, 0.712)
- command procedure of hypermesh
  - GEOM → CREAT NODE → type in
  - 2D → PLANES → NODES
  - automesh → interactive
    → mesh → type (mixed)
    → biasing
  - 3D → spine → on spin '200'
    → angle '360'

saved file of M_ILS

- IWS model



collector: create IWS
color red
material IWS

creat node
⑤ (-0.0475, 0.724)
⑥ (0.0475, 0.724)

can be chosen node ② and ④ created in constructing model section ILS

Fig. 2b IWS model
2D definition

- IBS (inner barrier solid) section

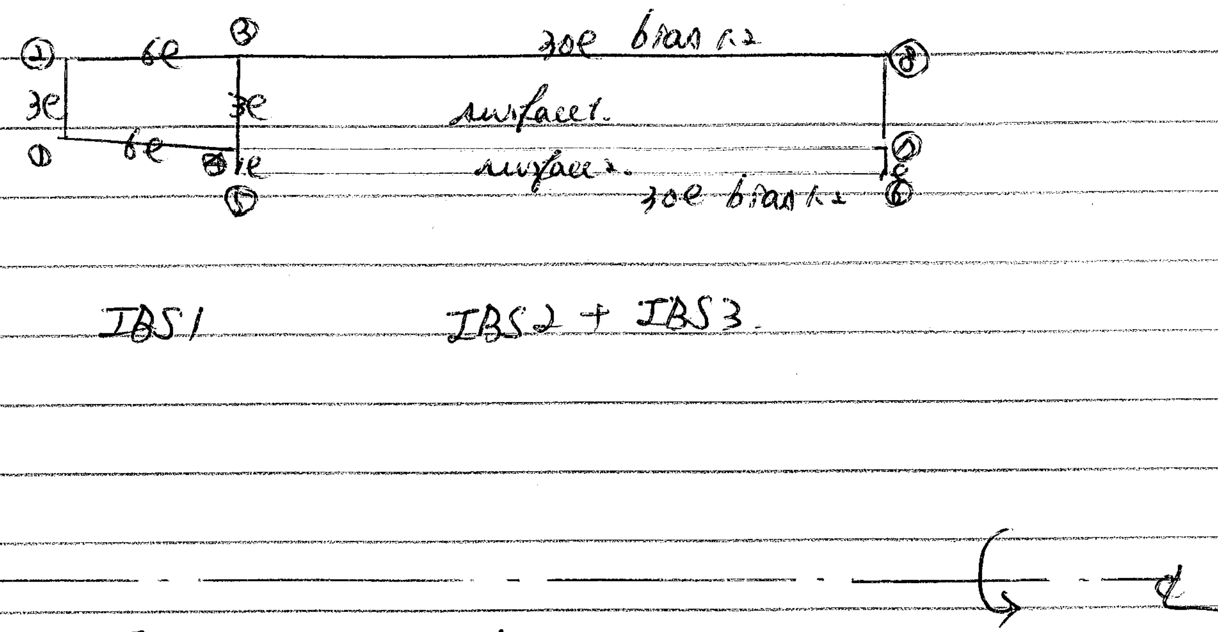
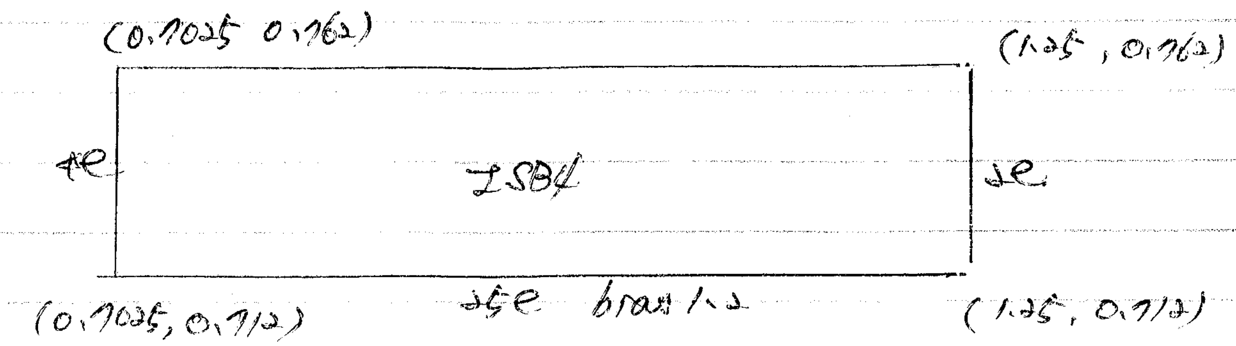


Fig. 27, IBS model composition
(composed of IBS1, IBS2, IBS3)

IBS model section was seperated to IBS1, IBS2, IBS3 because of connectivity of elements.

① (−0.0475, 0.734)
② (−0.0475, 0.762)
③ (0.0475, 0.762)
④ (0.0475, 0.724)
⑤ (0.8475, 0.712)
⑥ (0.7025, 0.712)
⑦ (0.7025, 0.724)
⑧ (0.7025, 0.762)



QI 10/2/2000 → coarse.

Fig. 28 ISB 3.4

- ISHB1. (inner barrier shell element) section.

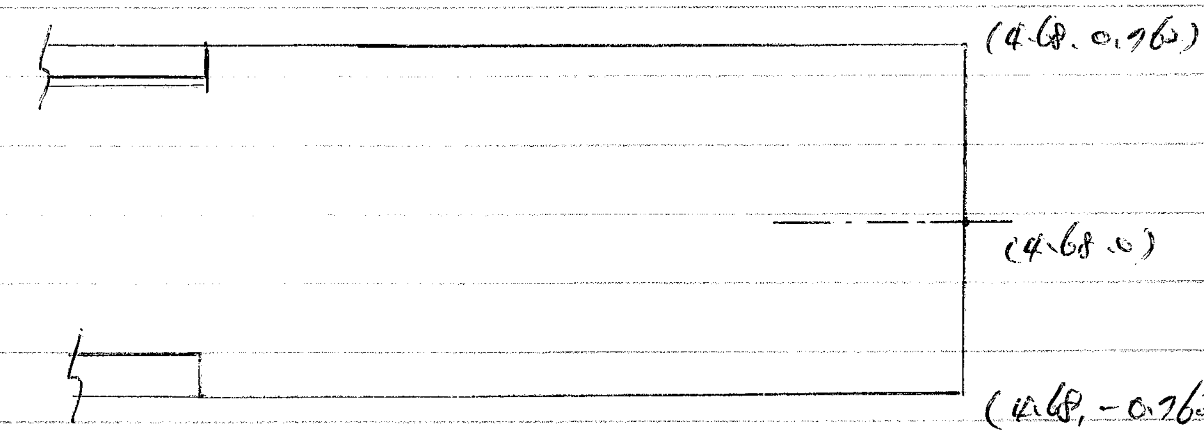


Fig. 29 ISHB1

- connection between solid element and shell element

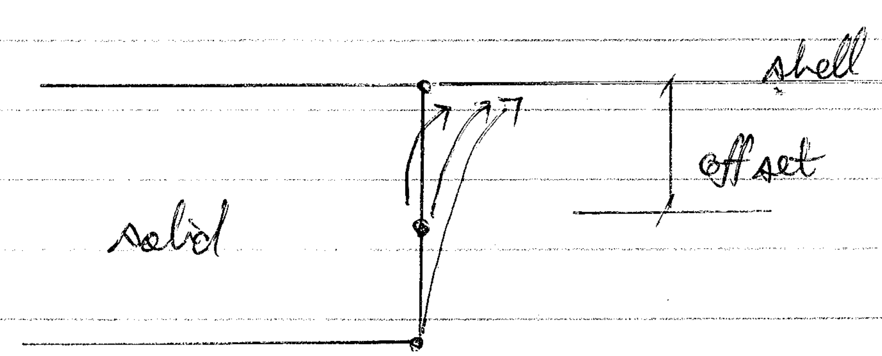


Fig. 30 element connection.

- Temporary boundary condition of inner barrier.
  To examine effect of welding (resultant residual stress) temporary boundary conditions are assumed as shown (proposed by Dr. Gute)

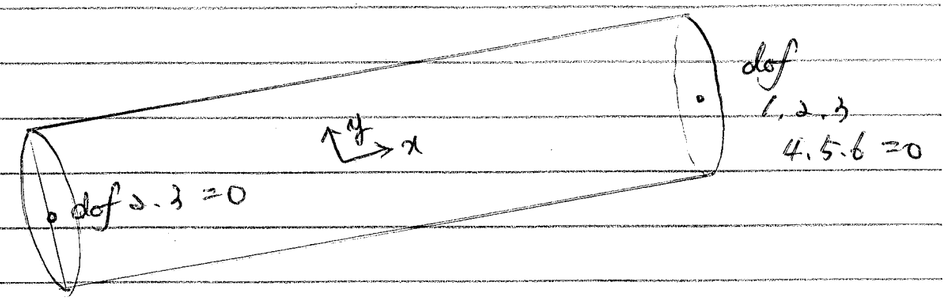


Fig. 31. Assumed temporary boundary conditions.

◎ Goal of the analysis (Proposed by Dr. Gute)

1. Thermal expansion stress generated between the inner & outer barriers of the WP after fuel has been emplaced.
2. Welding process for the inner barrier lid
3. Welding process of the outer barrier, inner lid.
4. Welding process of the outer barrier, outer lid
5. rockfall.

Doug Gute 10/2/2000

Aug. 5. 12:30 ~ 22:45 (Sat.)
Travel from San Antonio to State College.

Doug Gute 10/2/2000

Aug. 7. 2000 13:00 ~ 15:00

◎ Make abstract of working at CNWRL.

- Examined Reports.
  (1) Stress corrosion of Drip Shields, the Waste Package Outer Barrier and the Stainless Steel structural material.
  (2). Design Analysis for UTC Waste Package.
  (3). Design Analysis for Ex-container Components.
  (4). Rock Impact effects on 21-PWR nuclear Fuel Storage ~~Tank~~ TTC Container
  (5) Waste Package Phase II Closure Report
  (6) Waste Package Material Properties.
- Focus of modeling
  (1) residual stress induced by welding
  (2) rockfall
  (3) boundary conditions { heating boundary, structural boundary
  (4) resultant stress intensity.

standard analysis
(welding effects)
coefficient defined CRIMS MEO
(as to be mentioned)
I E f
k c ρ α E ν S_y

↓

result stress intensity factor ↔ compare with
not initial condition arithmetic result.

explicit analysis
rock shape
rock drop
height
attack point

↑ structural boundary conditions

combined comprehensive result stress intensity for
various parameters.

Fig. 32. Simulation Scheme

* parameter
anomaly
$\Delta V = V \times 0.15$
($6 \sim 10$ m/min)

- Modeling consideration I

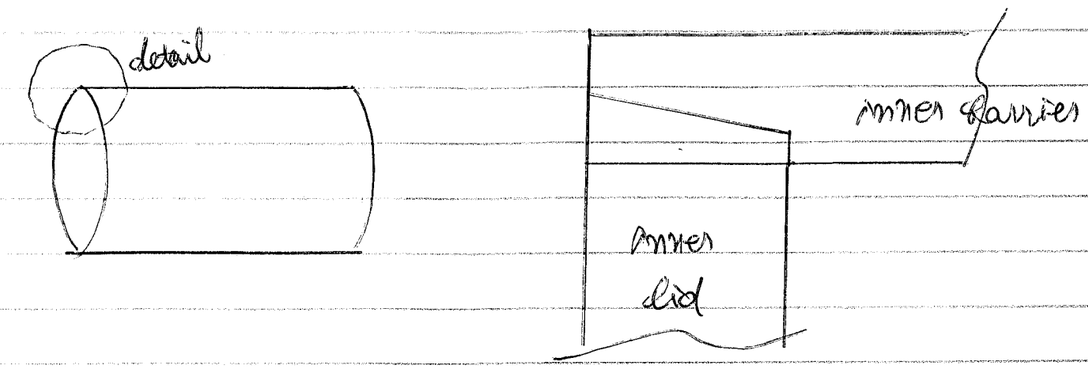


Fig. 33 inner lid and inner barries model geometry abstract.

- six passing layers are assumed
(referring to examined report 1.)
- ~~revealed~~ revealed problem
→ too many degree of freedom
→ determine effective region for entire analysis
→ use solid element on only effective region (25% length)
(refferring to examined report 4)

- Modeling consideration II

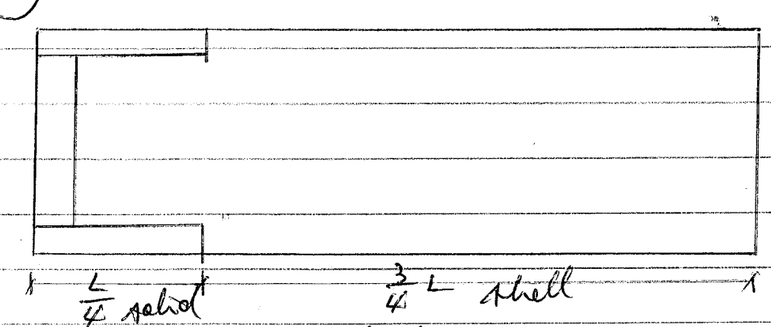


Fig 34. solid element region.

- Tracked down welding procedure
  - pass thickness : 0.1 in
  - travel speed : 1~8 in/min

  ↓

  at least ≥1 welding layer required in heat transfer analysis

  ↓

  impossible.

- Main goal of analysis
  1. thermal expansion stress generated between the inner & outer barrier of the TSP after fuel has been emplaced
  2. welding process for the inner barrier, inner lid
  3. welding process for the outer barrier, inner lid
  4. welding process for the outer barrier, ~~outer barrier~~ outer lid DH 10/12/2000
  5. rockfall.

- Working procedure (proposed by Dr. Choi).

construct axisymetric analytical model

considering all passing layers ..... ignoring passing layers

↓

determine acceptible (effective) passing layers

more than 10 → construct solid model with a layer passing

less than 10 → use solid model considering determined passing layers

step welding → check differences ← simultaneous welding

large → requires another strategy

small → use solid model with simultaneous welding considering all passing layers.

substructure technique, matrix reduction .....

Fig 25. working Procedure.

Doug Choi 10/12/2000

Aug. 8. 2000 14:00 ~ 15:00

◎ meeting with Prof. Krauthammer.

- presenting about work at CNWRL
- order (advise) by Prof. Krauthammer
  - examine closed form equation deduced by past researches of similar structural shape.
  - travel of welding could be ignored by examining past researches of closed form equation.

Doug Ste 10/2/2000

Aug. 9. 2000 10:00 ~ 14:00

◎ surveying papers and texts in engineering library of Penn State.

Doug Ste 10/2/2000

Aug. 10. 2000 14:00 ~ 18:00

◎ Examine Part Report

BBA000000-01717-5705-00016 REV 00

(title: Waste Package Phase II Closure Method Report)

- objective
  1. prove that the shrink fit method of fabrication was a viable fabrication method to form the inner and outer barrier.
  2. determine how much contact was obtained between cylinders.
- passing layers (travel times)
  - meaning of minimum welding thickness of outer lid weld.

⇒ pass thickness ≒ 0.1 in/pass.

- typical weld pass ≒ 23 min
- whole weld ≒ 4hr = 240 min

  10 passes approximately

  (height of inner lid is 1 in.)

- for outer barrier
  - typical weld pass ≒ 20 min
  - whole weld time ≒ 22 hr ≒ 1320 min

    66 passes for entire welding

    ⇒ 0.606 in/pass

- model spec.
  - ① axisymmetric model → pass verification
  - ② full model → passing effect verification

    (solid element model, shell element model, substructure model) → mixed model.

- passing layers for 21-PWR WP

  95/2.54 ≒ 37 passes

◎ Geometry of element section IBS1, IBS2, IBS3

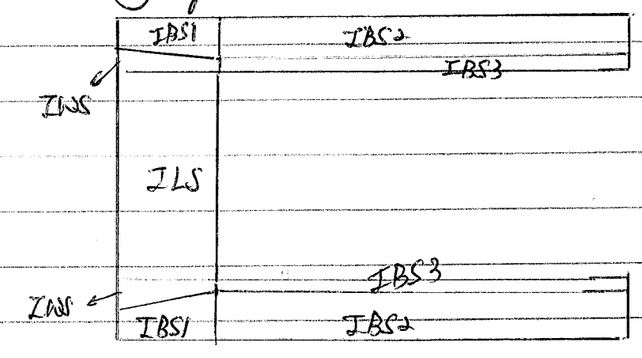


Fig 25. Detail Geometry of IBS.

Doug Ste 10/2/2000

Aug. 11. 2000 13:00 ~ 14:00

◎ Welding process modeling

$$\underbrace{\dot{q}^{pl}}_{\text{heat flux}} = \underbrace{\eta}_{\text{factor}} \sigma : \dot{\varepsilon}^{pl}$$

requires : · material's density
· specific heat
· inelastic heat fraction
(fraction of inelastic dissipation rate that appears as heat flux)

* fully coupled thermal stress analysis
⇒ nonlinear analysis procedure.
; requires the use of element with both temperature and displacement DOF.
{ sequentially coupled thermal stress analysis
* fully coupled thermal-stress analysis

孫昭昶
Doug Sohn 10/2/2000

Aug. 14. 2000 14:00 ~ 16:00

◎ Welding process modeling of loads.
· sequentially coupled thermal-stress analysis
thermal analysis → thermal results
→ structural analysis
* fully coupled thermal-stress analysis
thermal analysis ⇄ structural analysis.
· when affects each other strongly
(obtained simultaneously)
· requires the use of elements with both

temperature and displacement degree of freedom.
· { steady state
transient ⇒ to find residual stresses.
· movement definition.
- fixed
- automatic { allowable temperature change
creep response (can be excluded)
· precise unit is better.
· boundary condition (see heat input and boundary conditions)
· non-zero initial conditions.
· load : body flux (*DFLUX).

◦ Analysis trial.
- flux magnitude 100%
value 200.00

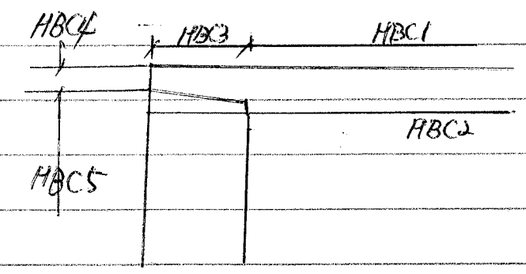


Fig. 36 Heat input and boundary condition

* initial condition = 200
* DFLUX (user subroutine - not defined in HyperMesh)

◎ Total numbers of nodes : 50334,
elements : 32581.

Doug Sohn 10/2/2000
孫昭昶

Aug. 15. 2000 14:00 ~ 15:00

- material of { outer barrier Alloy 22
  inner barrier SS 360 (N (standard steel)
- no slipping with contact element
  & friction will be considered
- paper surveying in library. 김지호 Dong Ho Kim 10/2/2000

Aug. 16. 2000 10:00 ~ 13:00

◎ material properties
{ inelastic mechanical properties
  heat transfer properties

- material properties dependent on some variables
  - when material properties dependen some variables, the variation of the properties with respect to the first variable must be given at fixed value of other variables, in ascending value of the second variables, then the third variables, and soon.

* ELASTIC
E ν θ
⋮

* EXPANSION
α_1 → because one value of thermal expansion coefficient has been given ⇒ independent of temparature

* ELASTIC
⋮

* PLASTIC
σ_{01} ε_{01} θ_1

σ_{11} ε_{11} θ_1
⋮
σ_{31} ε_{31} θ_1 ↑ θ_1
σ_{02} ε_{02} θ_2
⋮
σ_{32} ε_{32} θ_3 ↓ θ_2

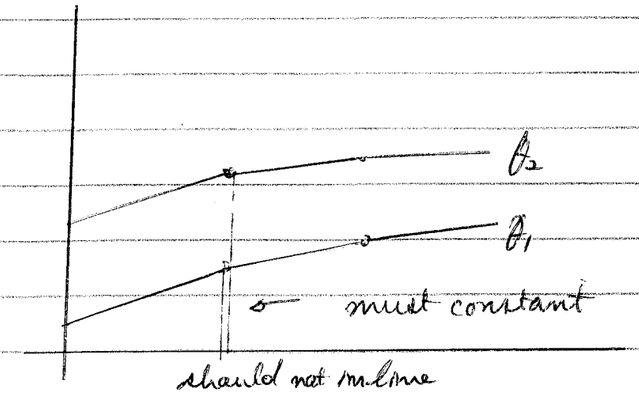


Fig. 37. Variation of properties.

- material properties for thermal expansion analysis
  - are defined as total expansion from a reference point.
  - can be specified as a function of temparature and/or field variables; and
  - can be specified directly in user subroutine
    * UEXPAN (in case of complicated function)
  - $\varepsilon^{th} = \alpha(\theta, f_\theta)(\theta - \theta^0) - \alpha(\theta^I, f_\theta^I)(\theta^I - \theta^0)$
- Thermal properties
  - thermal conductivities
    * CONDUCTIVITY
    - must be defined
    - can be linear or nonlinear (by defining it as a function of temparature)
    - specific heat
      $$c(\theta) = \frac{d\,U(\theta)}{d\theta}$$
      ⇒ is required for transient uncoupled heat transfer analysis - fully

coupled thermal-stress analysis.
· must appear in conjunction with the
* DENSITY option.
- latent heat
models large changes in internal energy during phase change of material.

Doug Suh 10/2/2000

Aug. 21. 2000 11:00 ~ 13:00
◎ Consideration about heat input per volume.
· volume of weld / time.

$$\left(\frac{\text{Heat input}}{\text{time}}\right)\left(\frac{\text{time}}{\text{volume of weld}}\right) = \left(\frac{\text{heat input}}{\text{volume of weld}}\right)$$

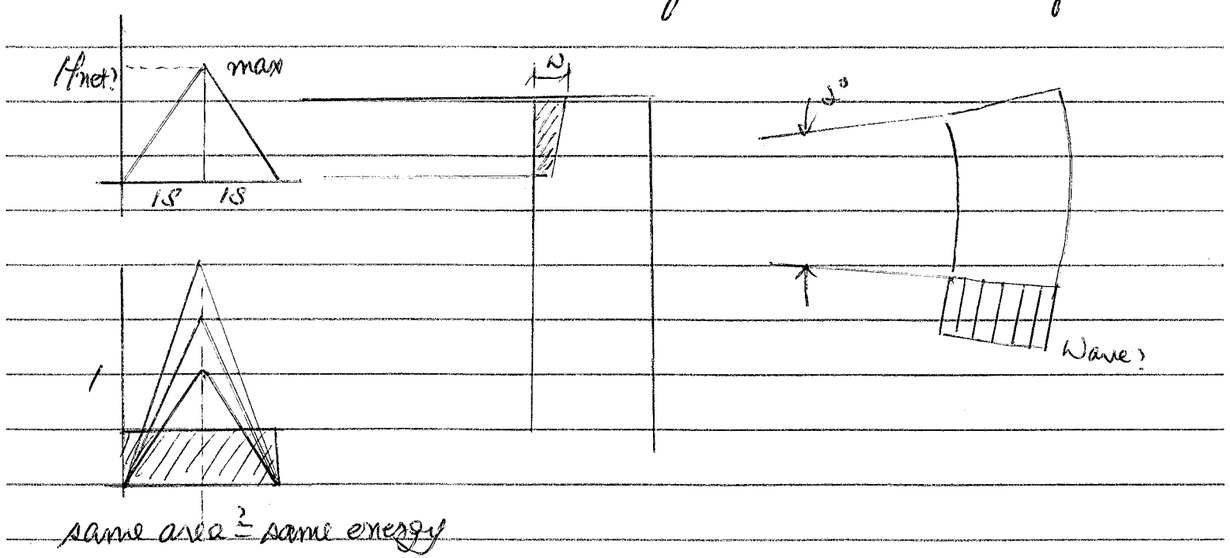


Fig. 38. heat input consideration

Doug Suh 10/2/2000

$$\text{time step} = \left(\frac{\text{weld length}}{\text{weld speed}}\right)$$

· total energy input limit

$$\text{total energy} = \int Q(t)\,dV$$

$$\frac{f_1 EI}{v} \Rightarrow \int dx$$

time and distance of travel must be considered simultaneously.

Doug Suh 10/2/2000

Aug. 23. 2000 11:00 ~ 13:00
◦ material input procedure
* DENSITY
* ELASTIC
* PLASTIC
* CONDUCTIVITY
* EXPANSION
◦ heat & thermal unit translation

$$°C = \frac{5}{9}(°F - 32)$$

· thermal conductivity
(BTU/hr.ft.°F.)
cf. 1 kcal/m·h·°C = 0.6720 BTU/hr.ft.°F
= 1.163 W/(m·K)

· thermal diffusivity

$$ft^2/hr = \frac{TC\ (BTU/hr.ft.°F)}{\text{density}\ (lb/ft^3) \times \text{specific heat}\ (BTU/lb.°F)}$$

Doug Suh 10/2/2000

Aug. 24. 2000 Mail communication with Dr. Gute.

HC Aug 24 2000

Dear Dr. Gute,

How are you doing?
I'm almost finishing paper searches about welding analysis of WP and it has some ambiguity because I can hardly find similar case.
Anyway, searching papers can let me make the schedule table and workscopes between you and me. It will be sent to your by email after I report it to Dr. Krauthammer. And then, you can examine works related my 30% participation and your 50% participation.

I have received a transfered email from Dr. Krauthammer originally composed by you. In that there were included that the deadline of dripshield and waste package project was expanded to September. I think Dr. Krauthmmer regards 'Waste Package' as welding analysis which you and I are doing. But when I were working in CNWRL, you and Asad said that your deadline for the welding analysis including rockfall was Mar. 15, so you asked me the possiblity of finishing the analysis by Jan. 15. 2001.
Please clarify the deadline of work which I'm doing. As the thought of Dr. Krauthammer, if the real deadline is to the end of September, I can say same word which I have said in CNWRL-it would be impossible.

In next mail, I will send time schedule and workscopes, but before that I have to know the obvious dealine to make time table.

HC Aug 24 2000

I will wait your responding mail.

Best Wishes,

Hyungjin Choi,

P.S My contact details are as shown,

email ; hjchoi32@hotmail.com
address ; 212 Sackett, University Park, PA, 16802.
phone ; 814-863-9787

HC Aug 24 2000

Hyung-Jin:

It is good to hear from you.

We have had to make some scheduling and priority changes because of changes in our budget for the coming fiscal year.

As a result, we will have to conclude our waste package and drip shield work with Penn State by the end of September. At that time, I am hoping you will be able to provide us with a summary of what you found during the literature search and some FE analyses illustrating the effects of various weld modeling simplifications.

Please let me know if you have any other questions or require additional information.

Doug

HC Aug 24 2000

Doug Gute 10/2/2000

Aug. 25. 2000 14:00 ~ 14:30

- Meeting with Dr. Krauthammer.

conclusion;

Because the deadline of the project was shortened from Jan. 15. 2001 to Sept. 30. 2000, we must change the project aim. Doug Gute 10/2/2000

Aug 31. 2000 11:00 ~ 15:00

- Paper survey (look over) to adjust project goal.

HC Aug 31. 2000

1. Zhao, H; White D.R.; DebRoy T. "Current Issues and Problem in Laser Welding of Automotive Aluminium Alloys" International Material Reviews pp 238~266, 1999.
2. Doumanidis, Charalabas C, "Thermal Analysis and Design of Scanned Rapid Prototyping" ASME Heat Transfer Division HTD V317-2, Nov. 12~17 pp 341~348, 1995.
3. Boo, K.S., Cho, H.S., "Self-organizing fuzzy Control of Weld Pool Size in GMA Welding Process" Control Engineering Practice 26 DEC. pp 1007~1018, 1994 HC Aug. 31 2000
4. Midling, O.T., Grong, O., "Structural-property Relationships in Heat Affected Zone of Friction Welded Al-SiC metal matrix Composites." Proceedings of the International Conference on Advanced Composite Materials, Feb. 15~19. 1993

pp 1221~1226.
5. Chakravarti, A.P., Thiban, R., Bala, S.R., "Thermal Analysis of Engineering Structures by the Finite Strip Method." Canadian Journal of Civil Engineering V13 n6 pp161~168, 1986.
6. Manko, Zbigniew, "Cooling Characteristics of Bead-on Plate Welds." Metal Construction V.17 n3 178r~183r, 1985.
7. Dieter Radaj "Heat Effects of Welding - Temparature Field Residual Stress Distorsion" Springer-Verlag 1992.
8. General Electrics Corporate Research and Developement "Data Books - Heat Transfer and Fluid Flow"

Doug Gute 10/2/2000

Sept. 6, 2000
· Mail communication with Dr Gute.
- propose reduced project aim

HC Sept 6 2000 HC Sept 6. 2000

Dr. Gute :

I'm very sorry that we have to finish WP project by the end of September. When I was there, we discussed about the project aim and please let me write it again.
1. thermal expansion stress generated between the inner & outer barrier of the WP after fuel has been emplaced.
2. welding process for the inner barrier, inner lid
3. welding process for the outer barrier, inner lid
4. welding process for the outer barrier, outer lid
5. rockfall
At first, to accomplish above 5 aims, I have said that we need longer time over Mar. 15, the date of your deadline and you suggested that we can work successfully with my 30% and your 50% participation.
Now, however, I think that we must adjust the aims to make it be possible by Sept. 30.

HC sept. 6. 2000 HC Sept 6 2000

HC sept. 6. 2000 HC sept 6. 2000

Actually, among above aims, I think, most important thing is that how much residual stressess are resulted from welding. To calculate the effects of welding, we must simulate heat transfer effects of the WP, and for the limitation of time, I think, we have to choose only one item among the work shown below,
1. theorectical procedure search and arrangement in detail to accomplish whole aims.
2. preparing analytical details which is fittable to the given WP, especially material properties of structural analysis and heat transfer analysis.
3. residual stress analysis of inner tank considersing simulteneous welding and traveling welding, with the model of only one passing layers.

Please let me know your choice or another thoughts, if you have.

Best Wishes,

Hyungjin Choi

email ; hjchoi32@hotmail.com

HC Sept. 6. 2000 HC sept. 6. 2000

HC sept. 6. 2000 HC. sept. 6. 2000

Jin:

As I pointed out in my recent e-mail to you, we have had to make some scheduling and priority changes because of changes in our budget for the coming fiscal year.

As a result, we will have to conclude our waste package and drip shield work with Penn State by the end of September. At that time, I am hoping you will be able to provide us with a summary of what you found during the literature search and some FE analyses illustrating the effects of various weld modeling simplifications. Specifically, as best you can, we would like to have some illustrative examples that demonstrate the affects that various modeling assumptions have on the residual stresses calculated for the closure welds. For example, reducing the number of weld passes in the model by increasing the amount of weld material deposited during each welding pass. Or, changing the element size along the length of the weld and how that affects the heat input and cooling time boundary conditions. This study can be done using a simple geometry (as you proposed when you were here) instead of the actual WP dimensions.

Give me a phone call at 210.522.2307 if you think it would be beneficial to discuss these matters more thoroughly.

Doug

HC sept. 6. 2000 HC sept 6. 2000

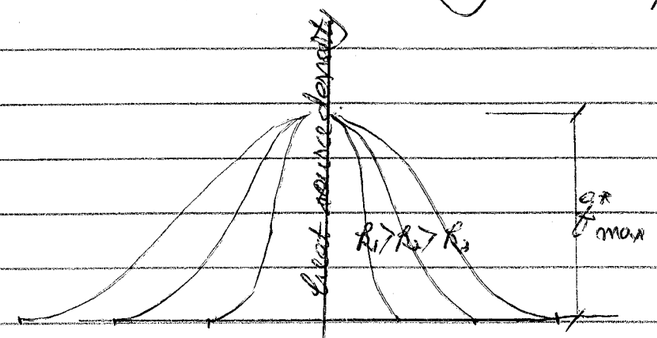
Doug Gute 10/2/2000

Sept. 10. 2000 14:00~16:00

- Spatial simplifications of the heat source.

The local concentration of the welding heat input suggests corresponding simplifications of the heat sources for the purpose of analysing the temperature field.

- concentration welding heat input



$$q^* = q^*_{max} e^{-kr^2}$$

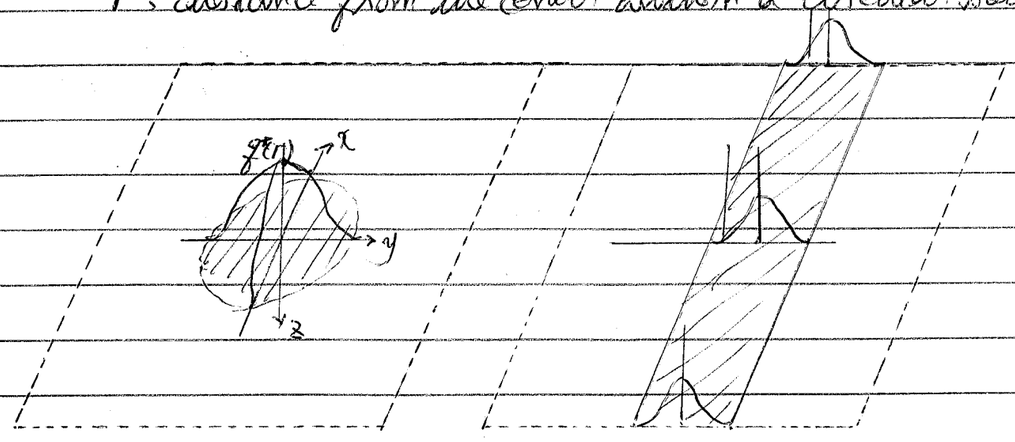
$$q^*_{max} = \frac{k}{\pi} q$$

Fig 39. Gaussian Distribution of Welding Heat input

q: effective output of heat source (J/s)

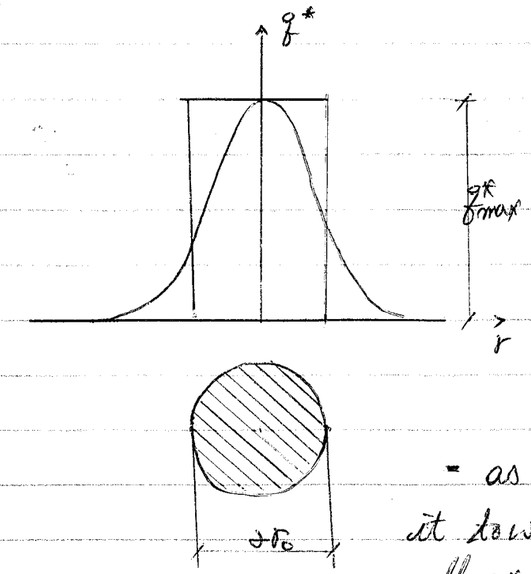
k: factor disinating the heat source concentration (1/mm²)
(width of the Gaussian distribution curve)

r: distance from the center within a circular source.



circular source strip source

Fig 40. Heat Input of Spot and Strip welding



circular source with normal distribution of heat source density q^* and equivalent circular source of equal output with constant heat source density q^*_{max}

- as the nature of Gaussian Curve, it towards to zero only at infinity, small q^* value can be regarded as negligible. HC. Sept. 10. 2000

Fig 41. Heat Source Density

$$\Rightarrow q^*_{min} = 0.01 q^*_{max}$$

- normal distribution source

$$d_n = \frac{2\sqrt{3}}{\sqrt{k}}$$ 〃

ZJTOA. 10/t. 2000

◎ Sep. 12. 2000 13:00 ~ 15:00

◎ Time simplification of heat source.

- the momentarily acting sources are characterized by the heat quantity (Q) which is introduced at that moment.
- the movement being assumed as linear and uniform (constant speed)
- the rapidity is related to the heat propagation only perpendicular to the weld. ZJTOA. 10/t. 2000

Sep. 16. 2000 09:00 ~ 13:00

° moving point source on the semi-infinite solid

- with moving source, the operative distance is also subdivided
- or, the differential momentary sources are arranged in succession in the direction of movement.
- the effect of the differential sources in individual points of the heat conducting solid now has to be added up, taking into account time and location of the occurrence of the momentary sources.
- the point type heat source is considered as moving uniformly and linearly (velocity v and heat output q), on the surface of semi-infinite solid

$$T - T_0 = \frac{q}{2\pi\lambda R} e^{-v(x+R)/2a}$$

(where, $\lambda = a\rho$)

$T - T_0$: temparature increment

R : distance from the point source

q : heat output

λ : thermal conductivity.

(referred in, Rosenthal, D, "The Theory of Moving Sources of Heat and its Application to Metal Treatments" Transaction of ASME 68 (1946) no. 11. pp 849~866.)

[illegible] 10/6 2000

Sep. 17. 2000 09:00 ~ 11:00.

° paper study and abstract arrangement.

Goldak, John; Gu, Maochi; Paramjeet, Kholal; Bibby, Malcolm "Computer Simulation of Welding Process", American Society of Mechanical Engineering, Material Division MD v 20 Nov. 26~30 1990. p 193~201.

- welding process are simulated with a 3D transient, coupled analysis of heat transfer, microstructure and thermo-elasto-plastic stress
- due to current limitations in modeling, the physics of the arc and weld pool for realistic welds, the heating effect of arc is modeled by prescribing either the temparature or the power density and flux in the weld pool.
- for low alloy steels, the microstructure evolution in space-time is modeled with a set of algebraic and ordinary differential equations.
- the thermo-elasto-plastic stress analysis is a large displacement, large rotation, finite strain analysis.
- the temparature from the heat transfer analysis drives the microstructure evolution and the thermal stress analysis.

[illegible] 10/6 2000

Sep. 25. 2000 09:00 ~ 13:00, 15:00 ~ 18:00

◎ Construction of finite element model to analyse welding

○ immense efforts items

1. The model should be designed three-dimensionally, at least in the weld area, in order to allow different cooling conditions in the interior and on the surface.

2. The process to be modeled is transient to a high degree, with extremely different field gradients depends on position and time because of the rapid heating-up and cooling-down events.

3. The process to be modeled is non-linear and temperature dependent to a high degree in respect to the thermo-mechanical behavior.

4. The momentary, local material behavior is dependent on the local thermal and mechanical stress and strain prehistory.

5. Material is molten during welding, in some cases, ~~also~~ also added to the component, and, as it solidifies change the connectivity of the component. HC 19/6 2000

6. Changes in state, and microstructure have to be simulated.

7. Defects and cracks, which may occur at critical points, make the continuum concept doubtful.

○ Simplification of the type.

1. Reduction of desirably three dimensional mechanical model to a two dimensional or even to a one-dimensional mathematical model, e.g. by assuming axisymmetry, by considering only the plate plane or only the plane of section perpendicular to the weld seam, by reducing the problem to a rod element or shrinkage force model.

2. Simplification of geometry, support and load conditions.

3. Symmetrization or periodization of the model.

4 Reduction of the non-linear thermoelastic-viscoplastic model to a linear thermoelastic model.

5. Reduction of transient process to quasi-stationary process.

6. Decoupling of the thermal and mechanical process.

7. Ignoring defect or crack formation.

8. Omitting the fusion and solidification phase as well

as the transformation processes which take place at elevated temperature and consequently at low yield stress

9. Registering the transformation at low temperature only globally in the specific heat and thermal expansion coefficient.

10. Ignoring creep and hardening as well as introducing simplification in yield laws.

11. Simplification of groove shape and layers structure

12. Replacement of heat source movement by momentary application of total heat quantity or by rapid heat source movement, ignoring heat propagation in the direction of movement.

13. Replacement of the temperature-dependent material characteristic value by temperature-constant averaged value in the decisive temperature range

14. Modeling of the formation of the residual stresses as a pure cooling process. - end of items.

Above 14 items are arranged by referring to 3 references as shown below. (on next page)

- Radaj, D., "Welding Stress Analysis with elastoplastic finite elements" Tran. 3rd Int. Conf. Struct. Mech. React. Technol, London, 1975, Vol. 5, Part M pp1~12.

- Masubuchi, K. "Report on the State-of-the-art of Numerical Analysis of Stresses, Strains and other Effects Produced by Welding." IIW-Doc. X-138-74.

- Radaj D. "Finite Element Analysis of Welding Residual Stress." International Conference on Residual Stress ICRS2 London, Elsevier Applied Science 1989 pp510-516

別紙2 Oct. 2, 2000

Sep. 26, 2000 13:00 ~ 16:00

- Searched paper arrangement.

Kim, Y. C., Fuji, A., Park, J. U., North, T. H. "Characterization of Residual Stress in Titanium / Aluminum Friction Welds." Proceedings of 1st International Conference on Processing Materials for Properties Nov. 5~10 1993, published by Minerals, Metals & Materials Soc. p 325-328.

7. In order to elucidate the characteristics of residual stress and plastic strain produced by the dissimilar friction welding operation, detailed FEM analysis was carried out.

2. During numerical modeling of residual stress and plastic strain formation in dissimilar joint, the distribution of σ_r in the radical direction produced by uniform cooling from 800°C, in material adjacent to the bondline in both substrates, provides an effective means for evaluation the accuracy of the computational procedure in dissimilar materials welds.

2. Heat transfer in the narrow zone, $z = \pm 20$ mm on either side of bondline promotes residual stress formation.

3. The σ_z distribution in the axial direction, is compressive in the central region of the component and is tensile at the component periphery. Specially, σ_z is tensile in the titanium substrate, except in regions extremely close to the bondline and in the radial direction, Limited plastic strain occurs in the circumference direction.

4. Severe plastic strain is produced in titanium substrates close to the bondline. This region in titanium close to the bondline has a hardness 1.6 times higher than in the base metal.

[illegible] Oct. 7. 2000

Sep. 27. 2000 15:00 ~ 17:00

⑨ Residual Stress of Ring and Pipe type Structure.

6 Ueda, Y.; Murakawa, H.,
" Application of Computer and Numerical Analysis Techniques in Welding Research." Transaction for JWRI 13 (1984) no. 2 pp 331 - 346.

Information potentially subject to copyright protection was redacted from this location.

The redacted material is from the reference information listed above.

Fig. 42 Temparature and stress profile transverse to butt weld during and after welding, structural steel (approx. St 37), infinite plate and plate strip submerged arc welded (solid - dashed) infinite plate strip electron beam welded (broken)

2. Houchens, A.F., Page, R.E., Yang W.H.
"Numerical Modeling of Resistence Spot Welding."
Numerical Modeling of Manufacturing Process
pp 117 ~ 129, New York ASME 1977

Oct.8.2000

Fig 4.3 Temparature (T), yield limit (σ_y) and equivalent stress σ_{eq} (after Von Mises) on inner surface of spot welded joint at end of cheating

Oct.8.2000

Information potentially subject to copyright protection was redacted from this location. The redacted material was two figures from the reference information listed above.

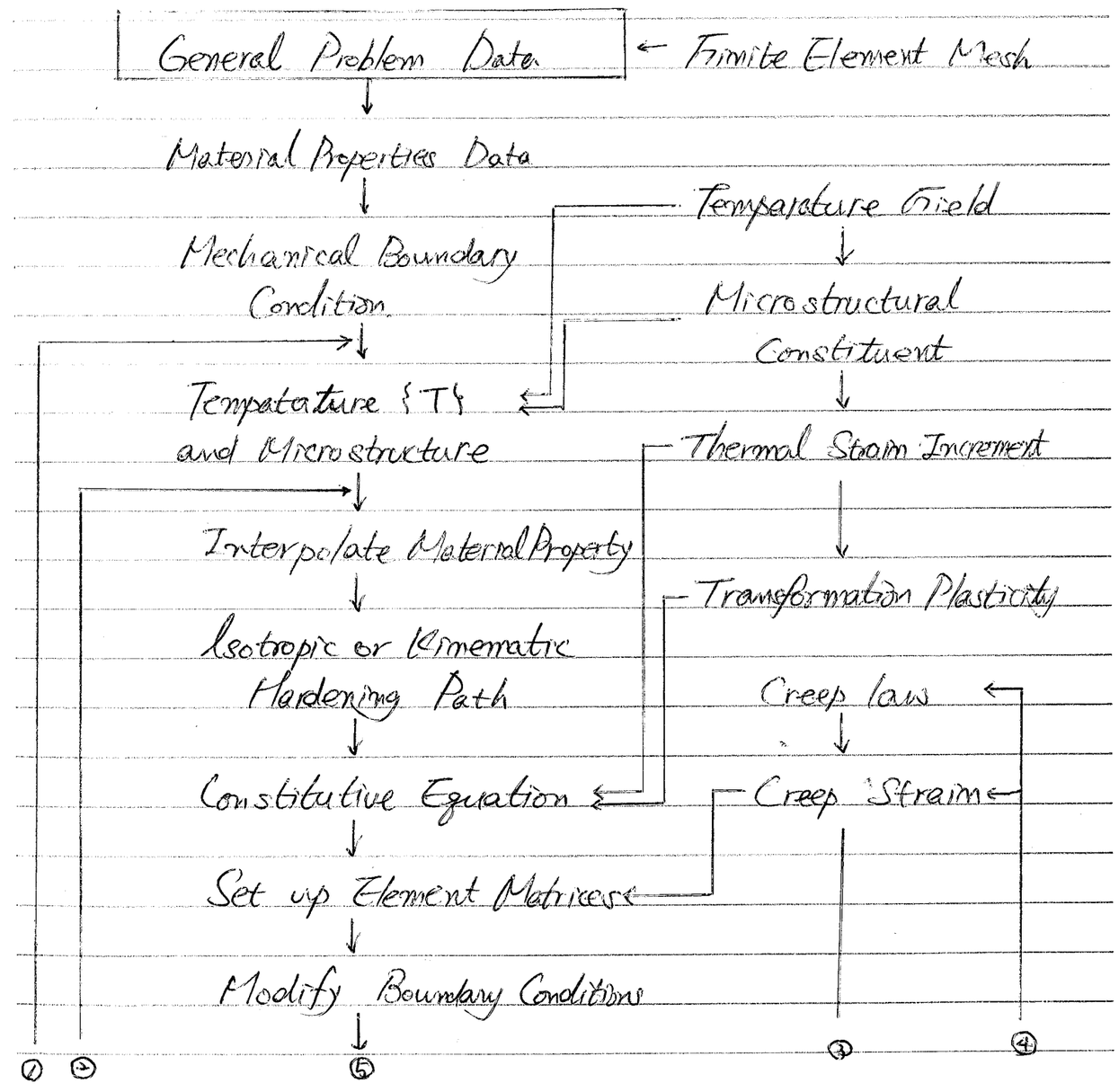
Oct8.2001

Fig. 4.4 Residual Stresses σ_r (radial), σ_t (transverse), σ_a, σ_{eq} of spot welded joint.

김재웅 Oct.8.2000

Sep. 29. 2000 11:00 ~ 15:00,

◎ Closure of Project oriented Paper Searching and arrangement Flowchart of Working Procedure for Welding Analysis by Finite Element Method.



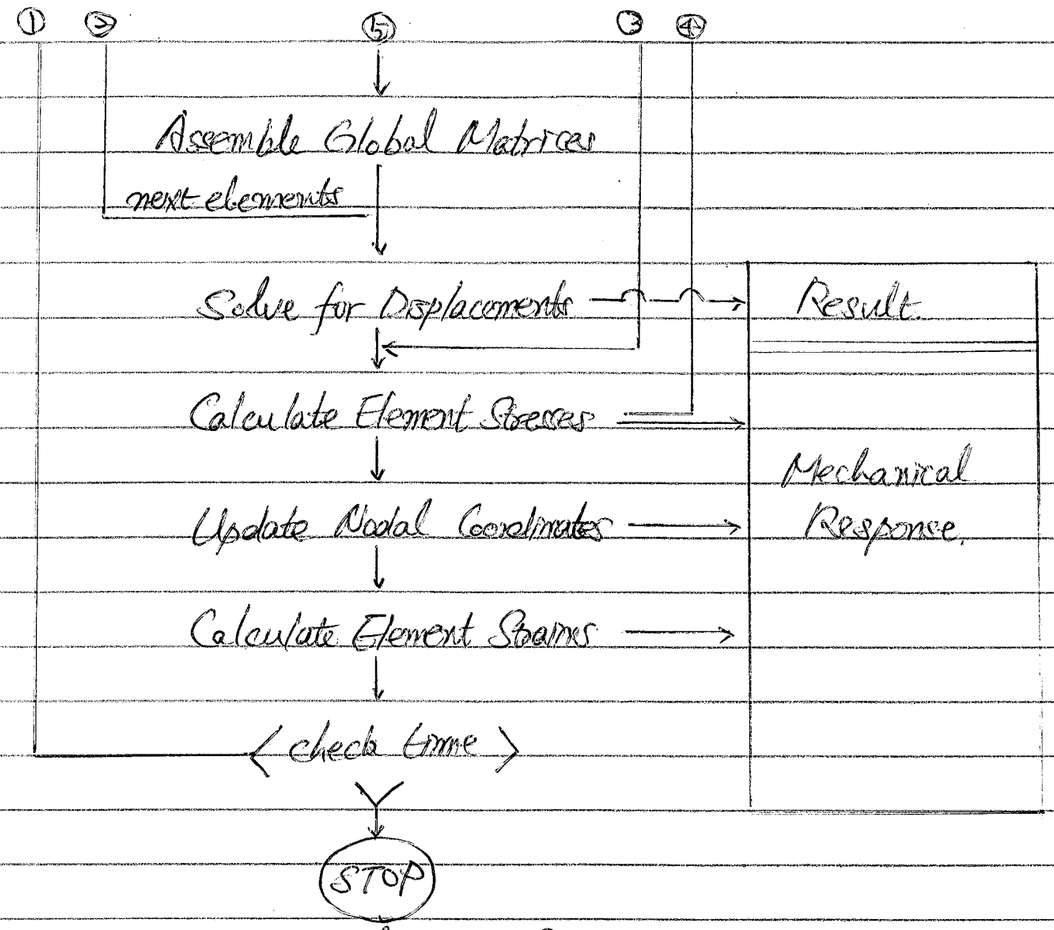


Fig 45. Analytical Procedure of Welding Process Heat Transfer by Finite Element Analysis

The flow chart was composed by referring to,
Buchmayr, B., Kirkaldy, J.S.,
"Modeling of the Temperature Field, Transformation Behavior, Hardness and Mechanical Response of Low Alloy Steels During Cooling From The ~~Auten~~ Austenite Region."
Journal of Heat Treatment, 8 (1990) no. 2 pp 127-136
H.C. Oct. 9. 2000
[illegible] Oct. 9. 2000

I have reviewed this scientific notebook and find it in agreement with QAP-001.
4-12-05