# 비선형 동해석

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- 예제 문제
  - Crash analysis
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    ▶ 재료 물성 및 특성 입력
    ▶ 요소망 생성
    ▶ 구속조건 설정
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    ▶ 후처리

### **INTRODUCTION (1)**

Crash analysis of body structure



#### **INTRODUCTION (2)**

표 7.7.1 암시적(Implicit)과 외연적(Explicit) 적분 알고리즘 비교

암시적(Implicit) 적분 알고리즘	외연적(Explicit) 적분 알고리즘
암시적(Implicit) 적분 알고리즘 • 선형 과도응답해석의 경우 큰 시간 스텝을 적용할 수 있음 • 비선형 과도응답해석의 경우 수렴성 확보를 위해 작은 시간 스텝을 사용해야 하는 단점이 있음 • 대규모 모델인 경우에는 메모리 사용량 및 하드디스크 용량의	외연적(Explicit) 적분 알고리즘 • 수렴성에 대한 문제 없이 해가 구해짐 • 소규모 모델인 경우에는 암시적 방법에 비해 해석 시간이 좀 더 많이 소요되나 대규모 모델에서는 상대적으로 유리함 • 시간 간격은 항상 임계 시간
제한이 있을 수 있음	신역포포 역한 따드포 경취

 $f(x_{n+1}, x_n, \dots) = 0$ 

 $x_{n+1} = f(x_n, \dots)$ 

#### **INTRODUCTION (3)**

- 내연적 시간 적분법 (HHT-α 이용: Newmark 방법의 일반화된 형태)
   1. 동적 평형방정식으로부터 구한 불평형력을 최소화 하는 방향으로 진행
   동적 평형방정식: Ma<sup>n+1</sup> + (1 + α<sub>H</sub>) [Cv<sup>n+1</sup> + f<sup>int,n+1</sup> f<sup>ext,n+1</sup>] α<sub>H</sub> [Cv<sup>n</sup> + f<sup>int,n</sup> f<sup>ext,n</sup>] = 0
   불평형력: g<sub>n+1</sub> = Mü<sub>n+1</sub> + (1 + α<sub>H</sub>) (C<sub>n+1</sub>ù<sub>n+1</sub> + f<sub>int,n+1</sub> f<sub>ext,n+1</sub>) α<sub>H</sub> (C<sub>n</sub>ù<sub>n</sub> + f<sub>int,n</sub> f<sub>ext,n</sub>)
  - 2. 변위 및 가속도 계산  $\mathbf{v}^{n+1} = \mathbf{v}^n + \Delta t \Big[ \gamma \mathbf{a}^{n+1} + (1-\gamma) \mathbf{a}^n \Big]$   $\mathbf{u}^{n+1} = \mathbf{u}^n + \Delta t \mathbf{v}^n + \frac{1}{2} \Delta t^2 \Big[ 2\beta \mathbf{a}^{n+1} + (1-2\beta) \mathbf{a}^n \Big]$
  - 3. 평형방정식 재구성

$$\mathbf{K}^{eff} \mathbf{u}_{n+1} = \mathbf{f}^{eff}$$

$$\mathbf{K}^{eff} = \frac{1}{\beta \Delta t^2} \mathbf{M} + \frac{(1+\alpha_H)\gamma}{\beta \Delta t} \mathbf{C} + (1+\alpha_H) \mathbf{K},$$

$$\mathbf{f}^{eff} = -\mathbf{f}^{int,0} + (1+\alpha_H) \Big[ \mathbf{f}^{ext,n+1} + \mathbf{f}^{nonmech,n+1} \Big] - \alpha_H \Big[ \mathbf{f}^{ext,n} + \mathbf{f}^{nonmech,n} \Big] +$$

$$\mathbf{M} \Bigg[ \frac{1}{\beta \Delta t^2} \mathbf{u}^n + \frac{1}{\beta \Delta t} \mathbf{v}^n + \left( \frac{1}{2\beta} - 1 \right) \mathbf{a}^n \Bigg] +$$

$$\mathbf{C} \Bigg[ \frac{(1+\alpha_H)\gamma}{\beta \Delta t} \mathbf{u}^n + \left\{ \frac{(1+\alpha_H)\gamma}{\beta} - 1 \right\} \mathbf{v}^n + \Delta t (1+\alpha_H) \Big( \frac{\gamma}{2\beta} - 1 \Big) \mathbf{a}^n \Bigg] + \alpha_H \mathbf{K} \mathbf{u}^n$$

#### **INTRODUCTION (4)**

- 외연적 시간 적분법 (중앙차분법 이용) 1. 시간 스텝을 n+1/2과 n, n+1 스텝으로 구분  $\Delta t^{n+1/2} = t^{n+1} - t^n, \ t^{n+1/2} = \frac{1}{2} \left( t^{n+1} + t^n \right), \ \Delta t^n = t^{n+1/2} - t^{n-1/2}$ 2. 스텝 n+1 에서의 변위는 n+1/2 스텝에서의 속도로부터 계산  $\dot{\mathbf{u}}^{n+1/2} = \mathbf{v}^{n+1/2} = \frac{1}{\Delta t^{n+1/2}} (\mathbf{u}^{n+1} - \mathbf{u}^n), \quad \mathbf{u}^{n+1} = \mathbf{u}^n + \Delta t^{n+1/2} \mathbf{v}^{n+1/2}$ 3. 스텝 n+1/2 에서의 속도는 n 스텝에서의 가속도로부터 계산  $\ddot{\mathbf{u}}^{n} = \mathbf{a}^{n} = \frac{1}{\Delta t^{n}} (\mathbf{v}^{n+1/2} - \mathbf{v}^{n-1/2}), \quad \mathbf{v}^{n+1/2} = \mathbf{v}^{n-1/2} + \Delta t^{n} \mathbf{a}^{n}$ 4. n 스텝의 가속도 a 는 공간상의 이산화를 통해 계산  $\mathbf{M}\mathbf{a}^{n} = \mathbf{f}^{n} = \mathbf{f}^{ext}(\mathbf{u}^{n}, t^{n}) - \mathbf{f}^{int}(\mathbf{u}^{n}, t^{n}), \ \mathbf{a}^{n} = \mathbf{M}^{-1}(\mathbf{f}^{ext}(\mathbf{u}^{n}, t^{n}) - \mathbf{f}^{int}(\mathbf{u}^{n}, t^{n}))$ 5.1~4과정 반복
- 외연적 시간 적분법의 임계 시간스텝

#### 예제: BEAM CRASH ANALYSIS

Simulate buckling of a tube using half tube mesh with symmetric boundary conditions.

The figure illustrates the structural model used for this tutorial: a half tube with a rectangular section (38.1 x 25.4 mm) and length of 203 mm.



- The tube thickness is 0.914 mm.
- $\rho = 7.85e^{-6} \text{ Kg/mm}^3$
- E = 210 GPa
- v = 0.33
- σ<sub>0</sub> = 0.206 GPa

- Initial density Young's modulus
- Poisson coefficient
- [a] Yield Stress

# **BEAM CRASH EXAMPLE**

#### HYPERCRASH 실행



# 유한요소해석 모델 불러오기



# 재료 물성 입력

1 PART

ALE

Support\*

Model LoadCase RADIOSS Tools Dat Browser Part Material Add to Material	<ul> <li>Review</li> <li>Create New</li> <li>Airbag matrix</li> <li>Create Template</li> <li>Composite</li> <li>Delete</li> <li>Connection</li> <li>Clone</li> <li>Elastic and</li> <li>Cross Reference</li> <li>Elasto-plas</li> <li>Mesh Support</li> <li>Honeycomi</li> <li>Lock</li> <li>Hydrodyna</li> </ul>	erial and Fabric Hyperelastic tic Johnson-Cook (2) b Zerilli-Armstrong (2) mic Hyd. Elasto-plastic (3)		Model > Material 클릭, 마우스 우클릭 후 Create New > Elasto- plastic > Johnson-Cook (2) 클릭
	UnLock Rock and C	concrete	2	재료 물성치 입력 [RHO_l]: 7.85e-6 [E]: 210
Title Local Unit System	2 New MAT 2 None			[Nu]: 0.3 [a]: 0.206
[RHO_] Initial density*	7.85E-6			
[RHO_0] Reference density	0		!	
[E] Young's modulus*	210			
[Nu] Poisson's ratio	.3			Support* 하모이 겨이
[Iflag] Flag for input type	0: Classic input for Johnson-Cook parameter a,b,n is		3	
[a] Plasticity yield stress*	.206			'마우스 우클릭하여 "Select
[b] Plasticity hardening parameter	0		į	in graphics"서태
[n] Plasticity hardening exponent	0			in graphics 전팩,
[EPS_p_max] Failure plastic strain	0		) i	Include picked part ( 💊 )
[SIG_max0] Plasticity maximum stress	0			크리 ㅎ ㅁ데 서태
[c] Strain rate coefficient	0	Include picked parts		골락 후 포골 연락
[EPS_DOT_0] Reference strain rate	0			
[Fsmooth] Strain rate Smoothing		Add selected parts by box		
[F_cut] Cutoff frequency for strain rate filtering	0	Berrove selected parts by hox	i	
[Flag] Hardening coefficient(define between 0 and 1) $% \label{eq:flag} = \left( f_{1}^{2} + f_{2}^{2} + f_{1}^{2} + f_{2}^{2} + $		Remove selected parts by box		
[Chard] Hardening coefficient(unloading)	0: Isotropic model	Add selected parts of Tree		
[m] Temperature exponent	0		!	
[T_melt] Melting temperature	0	- Remove selected parts of Tree		
[rhoC_p] Specific heat per unit of volume	0	Add selected parts of Browser	i	
[T_r] Room temperature	0			
Heat		- Remove selected parts of Browser		
[ICC] Strain rate computation	0: Default set to 1		i	

Clean selected part(s)



Model	LoadCase	RADIOSS Tools	Dat	6,6	Review	•	1			
E Br	owser			6	Create New	•	Airbag	Þ		
🔵 Pa	rt				Create Template	Þ	Line	Þ	1	
🔏 Ma	aterial			×	Delete		Surface	Þ	Pcompp	
🕬 🕴 Pro	operty				Clone		Volume	•	Shell (1)	

<b>D</b>	
HELL	
6	3
Title	New PROP 3
Local Unit System	None
[Ismstr] Flag for shell small strain formulation	0: Use value in /DEF_SHELL
[Ishell] Flag for 4 node shell element formulation	0: Use value in /DEF_SHELL
[Ish3n] Flag for 3 node shell element formulation	0: use value in /DEF_SHELL
[Idrill] Flag for drilling degree of freedom stiffness	0: No
[P_thick_fail] Percentage of through thickness integration	0
[hm] Shell membrane hourglass coefficient	0
[hf] Shell out of plane hourglass	0
[hr] Shell rotation hourglass coefficient	0
[dm] Shell membrane damping	0
[dn] Shell numerical damping	0
[N] Number of integration points through the thickness	0
[Istrain] Flag to compute strains for post-processing	0: Use value in /DEF_SHELL
[Thick] Shell thickness*	.914
[Ashear] Shear factor	0
[Ithick] Flag for shell resultant stresses calculation	0: Default set to value defined with /DEF_SHELL
[lplas] Flag for shell plane stress plasticity	0: Default set to value defined with /DEF_SHELL
Support*	1 items



#### 요소 생성 강체



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TI

<u></u>	<u> </u>		
<b>///</b> /////////////////////////////////	RBODY		
March Edition Marca 1	D	1	🔁 Mesh
Mesn Editing Mass N	Title	New RBODY 1	
	Local Unit System	None	💛 글닉, 너
Node	Master node in time History		Croate
Se Flement	Lagrange multipliers		
	Automatic master node		İ
🔵 Part 🔸	Flag for activate/deactivate in run	0: Not ON/OFF in current Engine file (or docked)	
NZ an orall of the second seco	[MASS] Mass	0	
👗 Rigid Body	[Jxx] JXX inertia	0	
	[Jyy] JYY inertia	0	2 Slave i
	[Jzz] JZZ inertia	0	
	[Jxy] JXY inertia	0	주 수 주물
	[Jyz] JYZ inertia	0	aranhi
	[Jxz] JXZ inertia	0	j grapni
	[ISPHER] Inertia	0: Default, set to 2	nodes
	[ISENS] Sensor	None	noues
	[NSKEW] Skew	None	: 선택
	[IKREM] Keep slave nodes in rigid wall		i L I
Add/Berrove nodes by picking selection	[ICOG] Center of gravity computation	0: Default, set to 1	I
Add/Remove hodes by picking selection	[loptoff] Manage domain decomposition of rigid body for	0: CPU cost of elements associated with rigid body is r	
Add/Remove nodes by ellipse selection	[lexpams] Manage connection through the rigid body bet	0: if the rigid body overlaps the AMS and non AMS dor	
	[Gnod_id] Slave nodes*	None	וה וב ר 💛
Add nodes by box selection			
			- / 선택 3
Remove nodes by box selection			
Add all nodes			
			l i
Include picked parts			
Add selected parts by box			
Remove selected parts by box		╪╪┥┥┰┰╒┽╪┥╪╖┥╎┞┼┾╪┿╪┿┾┾┾┾┿┿┿┿┿┿┿┿┿	• • •
		┥┧╫╫╫╫╫╫╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖╖	i i
Add selected parts of Tree			i i
Remove selected parts of Tree			
	HHHHH		
Add selected parts of Browser	HHHHH		
i			
Remove selected parts of Browser	HHHH		
Olean asked as do(a)	HHHH		
clean selected node(s)	HHP		

Editing > Rigid Body 마우스 우클릭 후 New 클릭 nodes 항목에서 마우 클릭 후 Select in ics 선택 > Add by box selection

ㅏ같이 tube 끝 절점 후 save 클릭

# 구속조건 설정 (1)



		<b>**</b>		
		2 acs		
OSS Tools	Data History	D	1	
		Title	New BCS 1	
	li li li	ALE formul.		
-121		Lagrange mult. formul.		
artion				
		[TX] X translation		
		[TY] Y translation		
		[TZ] Z translation	X	
		[RX] X rotation		
		[RY] Y rotation		
		[RZ] Z rotation		
		[Skew_id] Skew	None	
		[Gnod_id] Support*	1 items	
		[Gnod_id] Support (Advanced selector)		
H				

LoadCase > Boundary Condition 클릭, 마우스 우클릭 후 Create new 클릭 <sup>2</sup> TX 제외하고 모두 체크 <mark>3</mark> 앞서 제작한 Rigid 요소의 Master node 선택 후 save 클릭

# 구속조건 설정 (2)



# 구속조건 설정 (3)



## TUBE 속도 설정



# 접촉조건 설정

LoadCase RADIOSS Tools Data Hi	istory ≪ Review Create Create X Delete F Data H Clone Chang	V V V V V V V V V V V V V V V V V V V	th sliding (Type 1) n (Type 2) Type 3) ype 5) ody (Type 6) 7)	LoadCase > Contact Interface클릭, 마우스 우클릭 후 "Multi usage (Type 7) 클릭 Self Impact 체크
				👎 [Stfac] : 1
2		1		[Gapmin]: 0.9
Title		New INTER 1		
Self Impact				
Local Unit System		None O: Classical		<sup>:</sup> [Mast id]·모뎈 선택
listfl Stiffness defini	ition	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[Ithe] Heat contact				
[igap] Gap/element o	ption	0: Default, set to value defined in /DEFAULT/INTER/TYPE		i
[Fpenmax] Maximum	fraction of initial penetration	0		
[Ibag] Vent hole clos	sure when contact	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[idel] Node and segn	nent deletion	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[lcurv] Slave gap wi	th curvature	0: No curvature		i
[ladm] Local curvatu [Stfac] Scale factor [dtmin] Limiting noda	re flag for stiffness I time step	0: Not activated 1 0 0		
[Irem_gap] Flag for o	deactivating slave nodes if element s	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[Irem_12] Flag for de [Gapmin] Min. gap fo 10 II BCI Bound. coi	activating the slave node, if the sam or impact activ. nd. deactivation	0: default, set to the value defined in /DEFAULT/INTER/T .9		
[Inacti] Stiffness dea	activ. (init. penetration)	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[VisS] Critical dampi	ng coeff. on interface stiffness	0		
[VisF] Critical dampir	ng coeff. on interface friction	0		
[Tstart] Start time		0		
[Tstop] Stop time		0		i
[Bumult] Sorting fact	tor	0 0. Statia Caulante		
[Fric] Coulomb friction		0. Static Coulomb		
[Iform] Friction penal	Ity formulation	0: Default, set to value defined in /DEFAULT/INTER/TYPE		
[Ifiltr] Friction filtering	)	0: No filtering		
[sens_ID] Sensor to	Activate/Deactivate the interface	None		
[fct_IDf] Friction coe	fficient with temperature function id	None		
[AscaleF] Abscissa	scale factor on FCT_IDK	0		
Ifric IDI Friction ider	tifier for friction definition for selecte	None		
■[Mast_id] Master sur ▶ [Mast_id] Master	surface (Advanced selector)	ISI INTER Group 8_01_PART		

i.

# 해석 케이스 설정



🖺 New

K Export

Print

Exit

🖺 New Model 🔰 Import



#### 해석 실행 (RADIOSS) Radioss2020 실행 2 앞서 제작한 모델 불러온 뒤 Radioss 2020 Run 클릭 HyperWorks Solver Run Manager (@DESKTOP-J07RQSL) × 2 File Edit View Logs Solver Co-simulation HyperWorks Help ã BOX\_TUBE\_Analysis\_0000.rad Input file(s): Options: Use MPI options Use SMP: -nt 2 Use solver control Schedule delay 8 Run Close





변위, 응력 등 결과 확인

#### 연습문제: IMPACT OF A ROD ON RIGID WALL

Figure 12.6.1 shows a cylindrical rod model to simulate a high velocity impact event in which the cylindrical rod collides with a rigid wall. The collision is modeled by imposing zero axial displacement prescribed at one end of the rod, while imposing an initial axial velocity of 8937 in/sec to all other nodes. A von Mises elastic-perfectly plastic material model with isotropic hardening is used. The length and radius at 80 micro-seconds after the impact are obtained and compared with the reference values. Nonlinear explicit transient analysis is performed and the initial mesh and deformed shapes at 40 and 80 micro-seconds after the impact are shown in Figure 12.6.2.





	Young's modulus	E = 17 msi
	Poisson's ratio	v = 0.35
Material data	Density	$\rho = 0.3224 \ lbm/in^3$
	Hardening Modulus	$E_T = 14.5 \text{ ksi}$
	Yield Stress	$\sigma_{\rm r} = 58 \ ksi$

#### Table 12.6.1 The deformed length and radius at t=80 µsec after impact

	Length [in]	Radius [in]
Reference	0.84	0.28
midas-NFX	0.84	0.26



Figure 12.6.2 Deformed shape of the rod at t=0, 40 and 80 µsec

# BEAM CRUSH ANALYSIS 쉘 요소

#### 예제: BEAM CRUSH ANALYSIS (1)



Figure 3.6.4-1 Average static crush force vs. section shape (All samples were the same mass and length)

#### 예제: BEAM CRUSH ANALYSIS (2)

Geometry information Length: 305 mm 70 mm square thickness 1.4 mm Average strength 247 MPa

b

С

d

e

$$P_{M} = 386t^{1.86}b^{0.14}\sigma_{Y}^{0.57}$$
$$P_{MAX} = 2.87P_{M}$$
$$P_{1} = 1.42P_{M}$$
$$P_{2} = 0.57P_{M}$$

а

#### 예제: 재료 특성

Some of the material properties required to predict the crush characteristics are:

- 1. Stress-strain properties representative of the material for large plastic deformation
- 2. Change in properties under dynamic loading conditions
- 3. Strain hardening
- 4. Ductility properties
- 5. The variability that can be expected for production steels



#### Stress-strain curves

# 유한요소해석 모델 불러오기



# 재료 물성 입력 (1)

616	Review	) I	
6	Create New	Airbag material	+
	Create Template	Composite and Fabric	•
×	Delete	Connection	•
	Clone	Elastic and Hyperelastic	•
l	Cross Reference	Elasto-plastic	Johnson-Cook (2)
	Lock	Honeycomb	<ul> <li>Zerilli-Armstrong (2)</li> </ul>
	UnLock	Hydrodynamic	Hyd. Elasto-plastic (3)
	Move entity(s) to	Rock and Concrete	Hyd. Johnson-Cook (4)
	See in Browser	Visco-elastic	Ductile damage (22)
	Group Selected Row	s Fluid	Ductile damage (23)
		Non turbulent flow	Plastic brittle for shell (27)
		Turbulent flow	Hill orthotropic (32)
		Other	Piecewise linear (36)
		User Material	Hill ortho. tab. (43)
			Cowper-Symonds (44)
			Zhao (48)

Heat



PLAS_TAB	
₩ M	
D	2
Title	New MAT 2
Local Unit System	None
[RHO_] Initial density*	7.85E-6 2
[RHO_0] Reference density	0
[E] Young's modulus*	240
[Nu] Poisson's ratio*	.3
[Eps_p_max] Failure plastic strain	0
[Eps_t] Tensile failure strain	0
[Eps_m] Tensile failure strain	0
[C_hard] Hardening coefficient	0
[F_smooth] Strain rate smoothing	
[F_cut] Cutoff frequency for strain rate filtering	0
[Eps_f] Maximum tensile failure strain	0
[VP] Strain rate choice flag	0: Strain rate are total strain rate
[fct_IDp] Pressure vs. yield factor function	None
[Fscale] Y-Scale factor for yield factor function	1
[Fct_IDE] Function identifier for the scale factor of Young mod	None
[EInf] Saturated Young's modulus for infinitive plastic strain	0
[CE] Parameter for Young's modulus evolution	0

# 재료 물성 입력 (2)





PROP ×		
SHELL		
Local Unit System	None	
[Ismstr] Flag for shell small strain formulation	0: Use value in /DEF_SHELL	
[Ishell] Flag for 4 node shell element formulation	0: Use value in /DEF_SHELL	_
[Ish3n] Flag for 3 node shell element formulation	0: use value in /DEF_SHELL	
[Idrill] Flag for drilling degree of freedom stiffness	0: No	
[P_thick_fail] Percentage of through thickness integration point	0	
[hm] Shell membrane hourglass coefficient	0	
[hf] Shell out of plane hourglass	0	
[hr] Shell rotation hourglass coefficient	0	
[dm] Shell membrane damping	0	
[dn] Shell numerical damping	0	
[N] Number of integration points through the thickness	0	
[Istrain] Flag to compute strains for post-processing	0: Use va	
[Thick] Shell thickness*	1.4 1	
[Ashear] Shear factor	0	
[Ithick] Flag for shell resultant stresses calculation	0: Default set to value defined with /DEF_SHELL	
[lplas] Flag for shell plane stress plasticity	0: Default with /DEF_SHELL	
Support*	h PART 2	
Save	Cancel	





RBODY	
Local Unit System	None
Master node in time History	
Lagrange multipliers	
Automatic master node	
Flag for activate/deactivate in run	0: Not ON/OFF in current Engine file (or docked)
[MASS] Mass	0
[Jxx] JXX inertia	0
[Jyy] JYY inertia	0
[Jzz] JZZ inertia	0
[Jxy] JXY inertia	0
[Jyz] JYZ inertia	0
[Jxz] JXZ inertia	0
[ISPHER] Inertia	0: Default, set to 2
[ISENS] Sensor	None
[NSKEW] Skew	None
[IKREM] Keep slave nodes in rigid wall	
[ICOG] Center of gravity computation	0: Default, set to 1
[loptoff] Manage domain decomposition of rigid body for RADI	0: CPU cost of elements associated with rigid body is not take
[lexpams] Manage connection through the rigid body between	0: if the rigid body overlaps the AMS and non AMS domains, t
[Gnod_id] Slave nodes*	21 items
[Gnod_id] Slave nodes (Advanced selector)	

🝟 Rigid body 생성 z X

# 구속조건 설정 (1)

21 items

BCS

Title

ALE formul.

Rotation

[Skew\_id] Skew

[Gnod\_id] Support\*

D



[Gnod\_id] Support (Advanced selector)

# 구속조건 설정 (1)



BCS		
D	3	
Title	New BCS 3	
ALE formul.		
Lagrange mult. formul.		
[TX] X translation		
[TY] Y translation		
[TZ] Z translation		
[RX] X rotation		
[RY] Y rotation		
[RZ] Z rotation		
[Skew_id] Skew	None	
[Gnod_id] Support*	1 items	

강체의 중앙 부분의 절점은 부딪히는 방향의 자유도를 제외한 모든 자유도 구속

## TUBE 변위 설정

IMPDISP		(DIR): 7 (translation) 선택
D	1	[[funct]: 새서
Title	New IMPDISP 1	
Local Unit System	None	
[Tstart] Start time	0	
[Tstop] Stop time	0	Rigid body의 바스터 설점
[DIR] Direction*	Z: (translation)	🥖 에 석용
[lfunct] Time function*	[2] New FUNCT 2	
[Scale_x] X-Scale factor	1	
[Scale_y] Y-Scale factor	1	
[lskew] Skew	None	
[Isensor] Sensor	None	
[Frame] Frame	None	i
[Icoor] Type of usage of the coordinate system	Cartesian coordinates	
[Gnod_id] Support*	] IMPDISP_group_7_of_NODE	
Runction Window		×
Function name : New FUNCT 2		
<sup>™</sup> <sup>™</sup> × 0.000000E+000 <b>*</b>		
Time Displacement		
100 <sup>-150</sup> i <u>sp!3680000</u> ≢+001		
-1.500000E+002	+	
: 0.000000E+000	5.000000E+001 1.000000E+002 Time	
Time: 0		
Displacement: b		
Validate		
	Undo Reference Save Cancel	

I

## 접촉조건 설정

TYPE7	
D	1
Title	New INTER 1
Self Impact	
ocal Unit System	None
Formulation	0: Classical
Istf] Stiffness definition	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[Ithe] Heat contact	
[Igap] Gap/element option	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[Fpenmax] Maximum fraction of initial penetration	0
[lbag] Vent hole closure when contact	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[Idel] Node and segment deletion	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[lcurv] Slave gap with curvature	0: No curvature
[ladm] Local curvature flag	0: Not activated
[Stfac] Scale factor for stiffness	1
[dtmin] Limiting nodal time step	0
[Irem_gap] Flag for deactivating slave nodes if element size < ga	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[Irem_i2] Flag for deactivating the slave node, if the same conta	0: default, set to the value defined in /DEFAULT/INTER/TYPE7
[Gapmin] Min. gap for impact activ.	.9
I_BC] Bound. cond. deactivation	
[Inacti] Stiffness deactiv. (init. penetration)	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[VisS] Critical damping coeff. on interface stiffness	0
[VisF] Critical damping coeff. on interface friction	0
[Tstart] Start time	0
[Tstop] Stop time	0
[Bumult] Sorting factor	0
[Ifric] Friction formulation	0: Static Coulomb
[Fric] Coulomb friction	2
[Iform] Friction penalty formulation	0: Default, set to value defined in /DEFAULT/INTER/TYPE7
[Ifiltr] Friction filtering	0: No filtering
[sens_ID] Sensor to Activate/Deactivate the interface	None
[fct_IDf] Friction coefficient with temperature function identifier	None
[AscaleF] Abscissa scale factor on FCT_IDK	0
[fric_ID] Friction identifier for friction definition for selected pairs	None 🕥
[Mast_id] Master surface*	1 items 2

Contact interface 생성 후 파라미터 설정 Self Impact: 체크 [Stfac]: 1 [Gapmin]: 0.9 [Fric]: 0.2 접촉 파트 설정

# 해석 케이스 설정

L S.No L 1

		Succession of the second	Control card 설정
RUN_NAME_NUMBER_LETTER			
RUN_NAME_NUMBER_LETTER			
Run Number	1		
[DT_STOP] Final time for run	4.01	İ	
Restart letter	: Default	i	
		<b> </b>	
ANIM_DT			
ANIM_DT			
[TSTART] Start time	0	ļ	
[TFREQ] Time frequency	0.01		
		ļ	
		İ	
		İ	
M ANIM_VECT			
S.No Variable name to be saved in animation file			
1 FOPT			
		İ	
		i i	
		<b> </b>	
ANIM VECT DESTYDE SUDDORT			
Variable name to be saved in animation file*	FOPT: Forces and moments for rigid bodies, rigid walls and sect		
		.	



모델 export 후 RADIOSS 에서 해석 실행

Contour Plot Displacement(Mag) Analysis system

후처리 (1)





Ζ Y х















Analytic solution

 $P_M = 386t^{1.86}b^{0.14}\sigma_Y^{0.57} = 30237 \text{ N}$   $P_{MAX} = 2.87P_M = 86780 \text{ N}$   $P_1 = 1.42P_M = 42936 \text{ N}$  $P_2 = 0.57P_M = 17235 \text{ N}$ 

Ideal graph



Crush Distance (in)





FEM solution  $P_{MAX} = 52128 \text{ N}$ 





예제에서 수행한 정 사각형의 정적 충돌 하중을 100%로 놓고, 나머지 형상 중 하나를 결정하여 평균 정적 충돌 하중을 구하시오.

AVERAGE STATIC CRUSH FORCE



Figure 3.6.4-1 Average static crush force vs. section shape (All samples were the same mass and length)