

Topology Optimization

Computational Design Laboratory
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한양대학교
HANYANG UNIVERSITY

CDL Computational
Design
Lab

OUTLINE

- **Lecture Goals**

- ✓ 2D & 3D 구조의 컴플라이언스 및 부피 최소화 문제와 고유 주파수 최대화 문제에 대한 위상 최적화를 수행하고 설계 결과를 분석한다.

- **Contents**

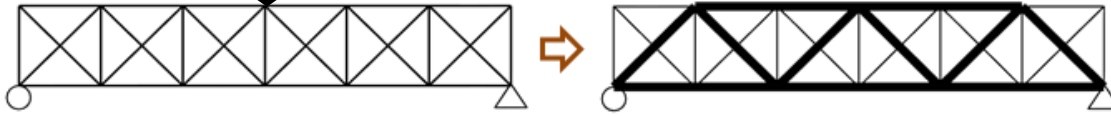
- ✓ 2D structure examples
 - : compliance minimization problem (single & multiple loads)
 - : volume minimization problem
 - : eigenvalue maximization problem
 - : symmetric condition problem
- ✓ 3D practical example
 - : automotive control arm optimization (volume minimization)

- 해석 프로세스

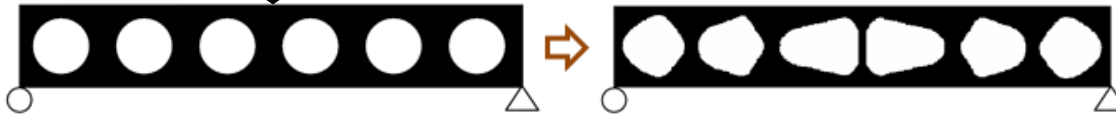
- 기하형상 생성
- 재료 물성 및 특성 입력
- 요소망 생성
- 구속조건 설정
- 하중조건 설정
- 최적설계 문제 정식화 및 최적설계 실행
- 후처리

TOPOLOGY OPTIMIZATION

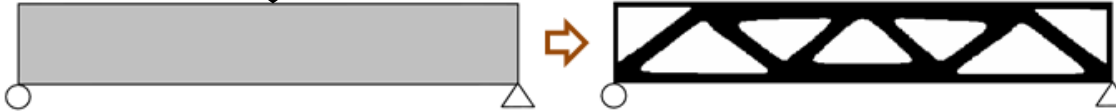
Size optimization



Shape optimization



Topology optimization



➤ 위상최적화란?

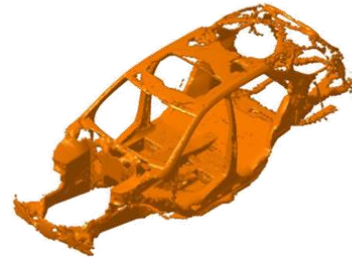
최적설계를 하고자 하는 설계영역의 구속조건과 설계변수를 설정하고 목적함수를 만족하는 최적모델을 생성하는 해석입니다

➤ 최적화 문제 구성

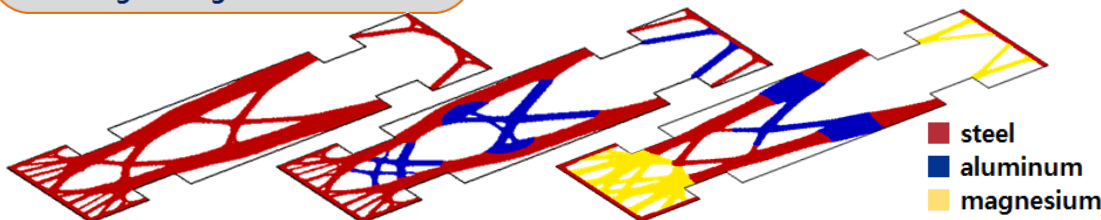
- 목적함수는 부피나 질량과 같이 줄이거나 키우고 싶은 값을 의미합니다.
- 구속조건은 변위나 응력처럼 만족해야 하는 설계조건을 의미합니다.
- 설계변수는 치수나 재료 특성처럼 결정해야 할 설계인자들입니다.



BIW design for weight reduction



Underbody design using light-weight material



■ steel
■ aluminum
■ magnesium

< 최적화 문제 구성 예 >

목적함수	부피 최소화
구속조건	변위제한 0.05mm
설계변수	요소 형상 밀도

TOPOLOGY OPTIMIZATION

표 5.11.1 목적함수에 따른 문제구성 종류

목적함수	설계 제약조건	관련 해석	제조조건(공통)
정적 컴플라이언스(최소)	부피비	· 선형 정적 해석	· 성형 방향 · 대칭 조건 (1~3축 대칭)
동적 컴플라이언스(최소)	부피비	· 주파수 응답 해석	
부피비(최소)	변위/응력	· 선형 정적 해석 · 주파수 응답 해석 (변위제약)	
평균 고유치(최대)	부피비	· 모드 해석	
부피비(최소)	모드	· 모드 해석	

표 5.11.2 재료 보간 방법

	SIMP solid isotropic material with penalization	RAMP ¹² rational approximation of material properties
보간식	$k_e(x_e) = x_e^p k_{e0}$	$k_e(x_e) = \frac{x_e}{1 + q(1 - x_e)} k_{e0}$
미분식	$\frac{\partial k_e}{\partial x_e} = p x_e^{p-1} k_{e0}$	$\frac{\partial k_e}{\partial x_e} = \frac{1 + q}{[1 + q(1 - x_e)]^2} k_{e0}$
관련해석	선형 정적	모달, 주파수 응답
벌칙계수	$p = 3.0 \sim 4.0$	$q = 5.0 \sim 6.0$

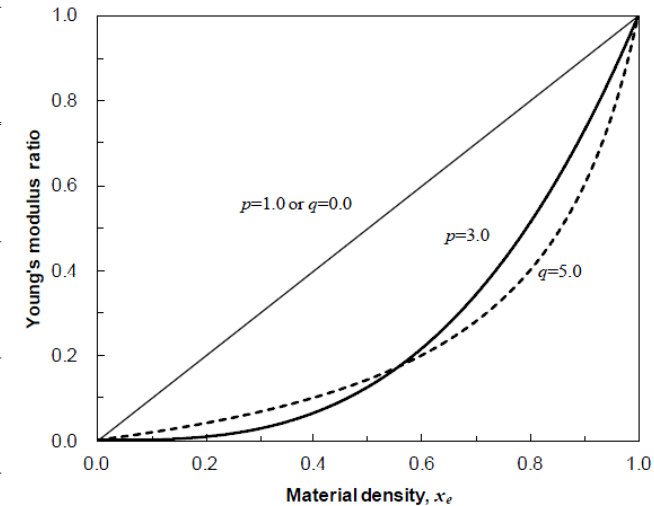


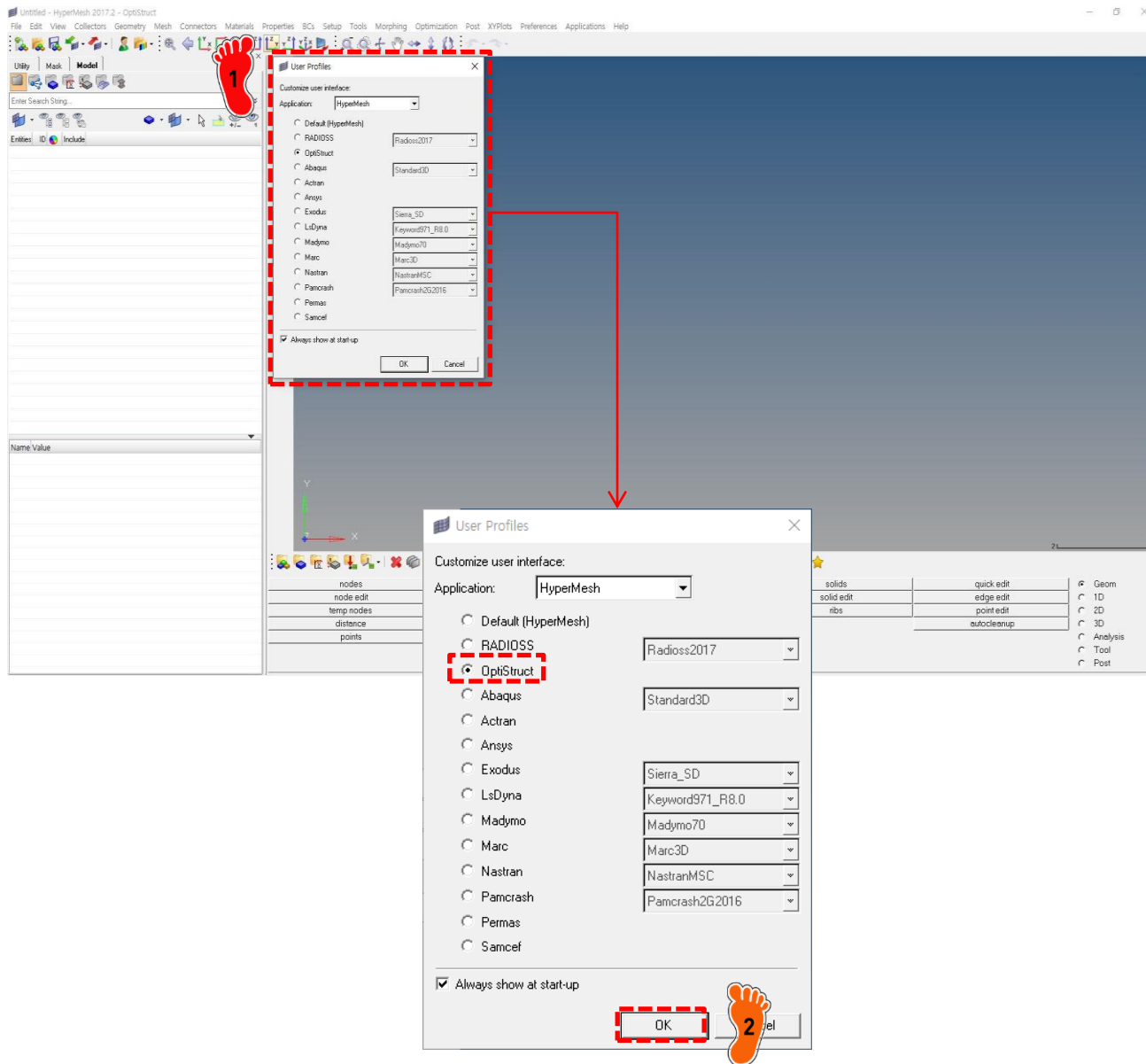
그림 5.11.1 재료보간모델별 밀도에 따른 강성비

2D STRUCTURE (단일 하중)

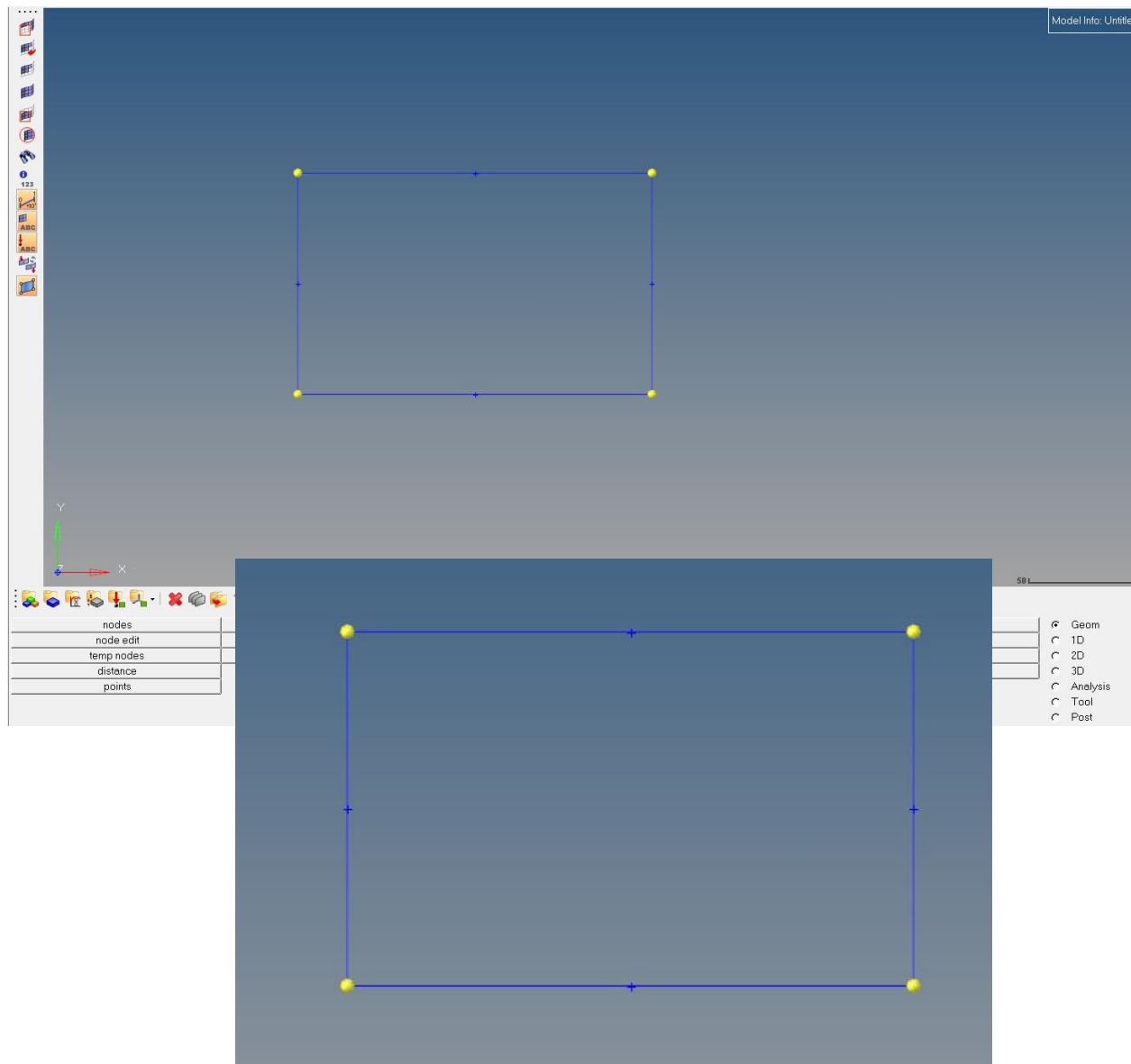
목적함수: 컴플라이언스 최소화
구속조건: 부피율



기하형상 생성 (1)



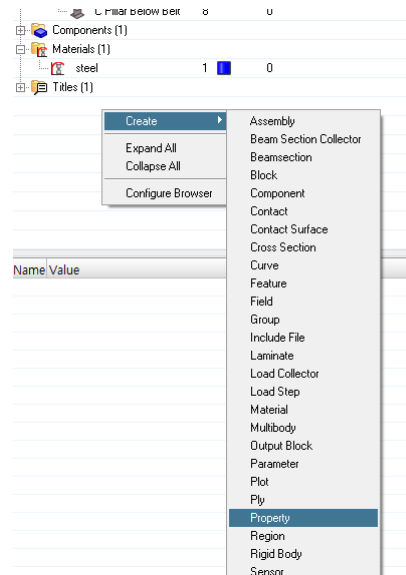
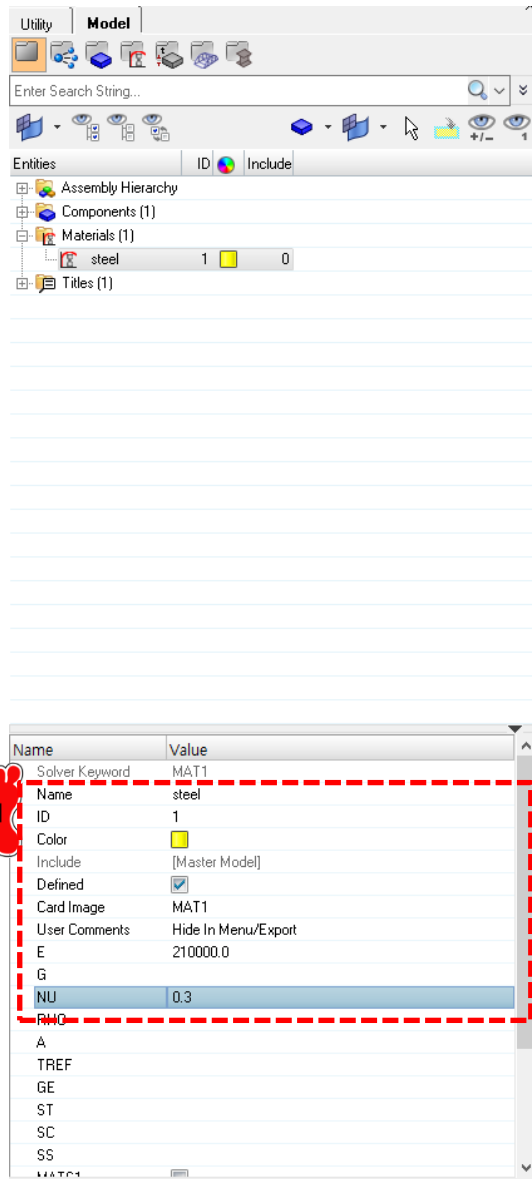
기하형상 생성 [2]



(0,0,0),(160,0,0),(160,100,0),
(0,100,0) 노드 생성
라인 생성

* Temp nodes > clear all

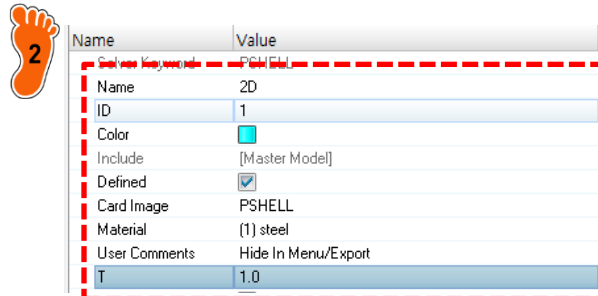
재료 물성 및 특성 입력



1 우클릭, Create > Material
Name > steel
탄성계수(E)
> 210 Gpa (210000 N/mm²)
푸아송비(NU) > 0.3
재료 생성

2 Create > Property
Card Image > PSHELL
Material > steel
T > 1mm
Name > 2D

Component에 특성 입력



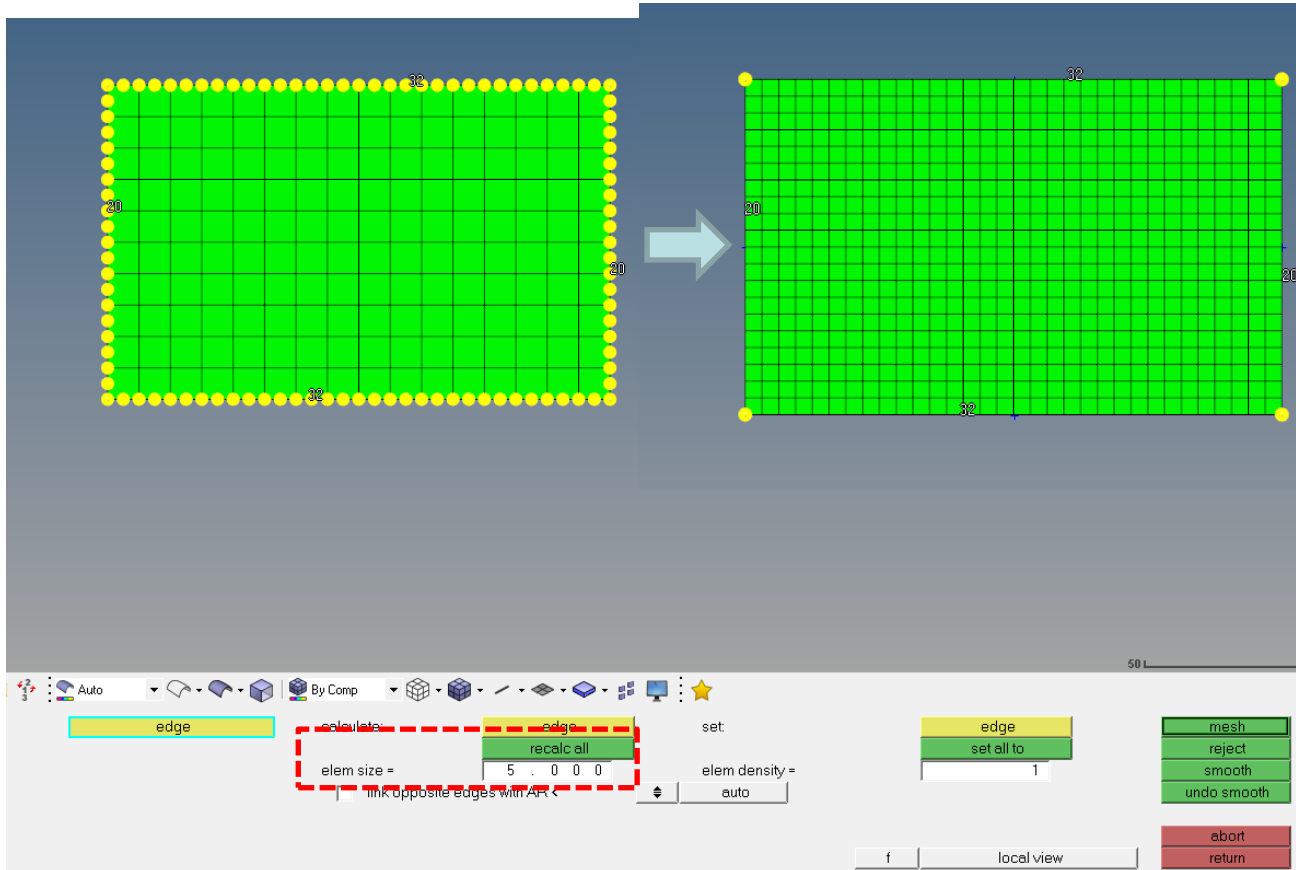
요소망 생성



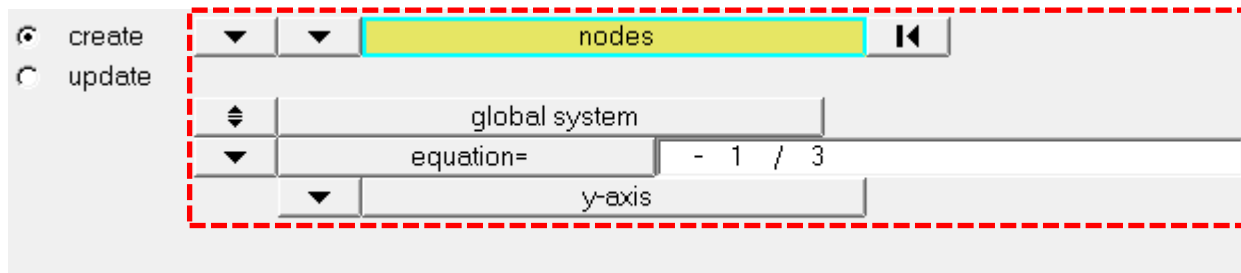
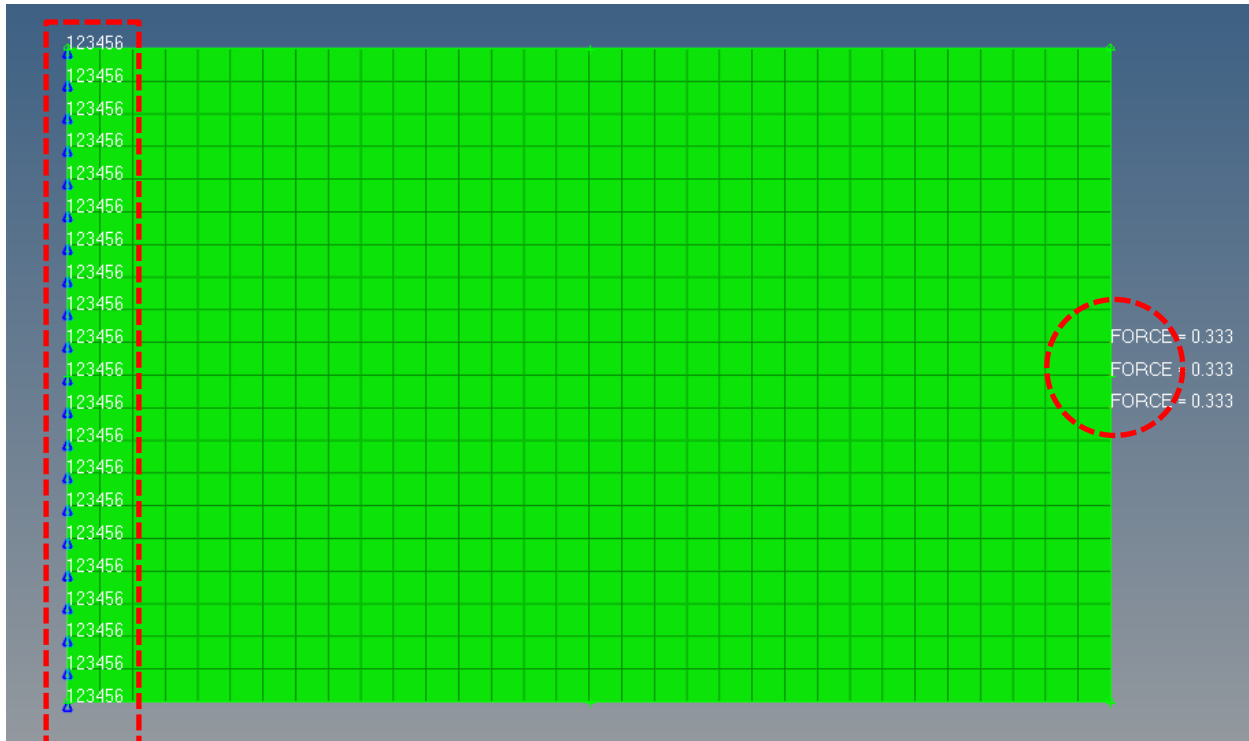
크기 5인 2차원 요소망 생성

2D > planes > 4개 line 선택 > create

Elem size > 5 > recalc all > mesh > return



구속조건 및 하중조건 설정



Load Collectors

Name > SPC

BCS > Creates >

Constraints

고정구속



Load Collectors

Name > load

BCS > Creates > Forces

가운데 3개 절점에 Y방향

단위하중 (-1/3N) 입력

Load steps

Analysis type

> Linear Static

SPC > SPC

LOAD > load

DESIGN VARIABLE SETTING

→ **Design variable**

→ **Responses**

→ **Objective**

→ **Dconstraints**

→ **Opti control**



Analysis > optimization >
topology

create



RESPONSE SETTING (1)

→ Design variable

→ **Responses**

→ Objective

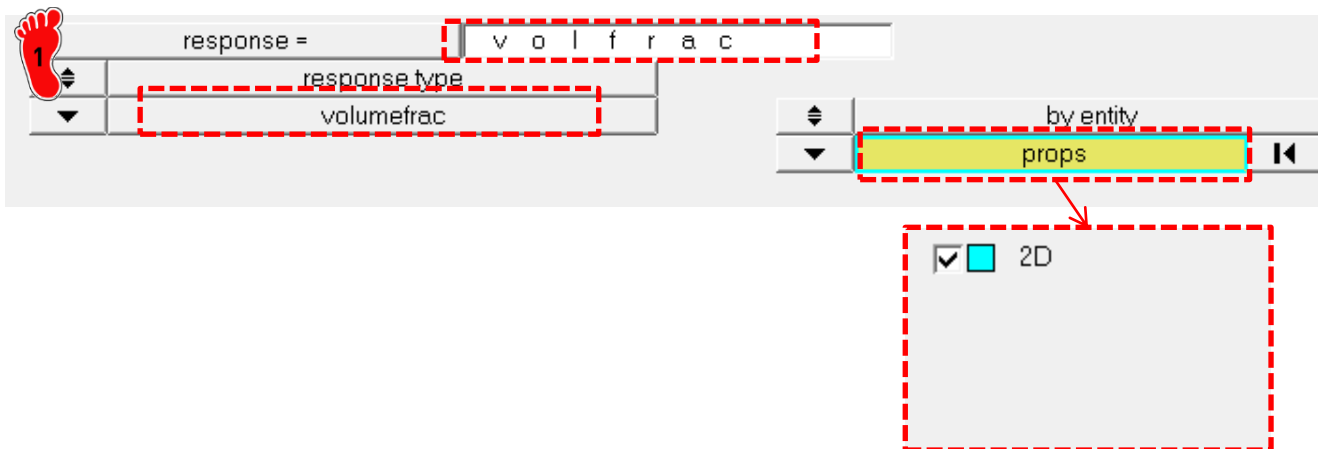
→ Dconstraints

→ Opti control



Analysis > optimization >
responses

create



RESPONSE SETTING (2)

→ Design variable

→ **Responses**

→ Objective

→ Dconstraints

→ Opti control



Analysis > optimization >
responses

create



loadstep1	1	0	0	0

OBJECTIVE SETTING

→ Design variable

→ Responses

→ **Objective**

→ Dconstraints

→ Opti control



Analysis > optimization >
objective

create



min

response =

W c o m p

CONSTRAINTS SETTING

→ Design variable

→ Responses

→ Objective

→ **Dconstraints**

→ Opti control



Analysis > optimization >
dconstraints

create



constraint =	v o l f
lower bound =	- 1 . 0 0 0 e + 2 0
upper bound =	0 . 3 0 0

response =	v o l f r a c
------------	---------------

☐ Wcomp
☐ volfrac

CONTROL SETTING



Analysis > optimization >
opti control

→ Design variable

→ Responses

→ Objective

→ Dconstraints

→ **Opti control**

DESMAX: Maximum number of design iterations

OBJTOL: 0.5% change in the objective function

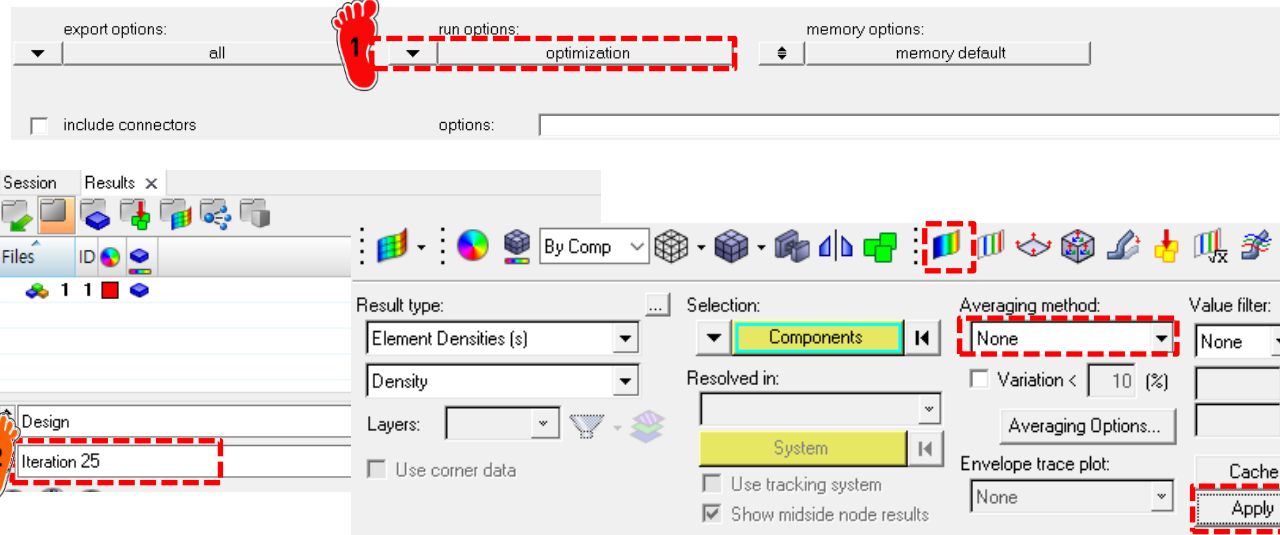


☒	DESMAX=	50	☒	OBJTOL=	0.005
☐	MINDIM=	0.000	☐	DELSIZ=	0.500
☐	MATINIT=	0.600	☐	DELSHP=	0.200
☐	MINDENS=	0.010	☐	DELTOP=	0.500
☒	DISCRETE=	3.000	☐	GBUCK=	0
☒	CHECKER=	1	☐	MAXBUCK=	10
☐	MMCHECK=	0	☐	DISCRT1D=	1.000

DISCRETE: Higher values decrease the number of elements that remain between 0 and 1.

CHECKER: Checkerboard control option. (0 = no checkerboard control)

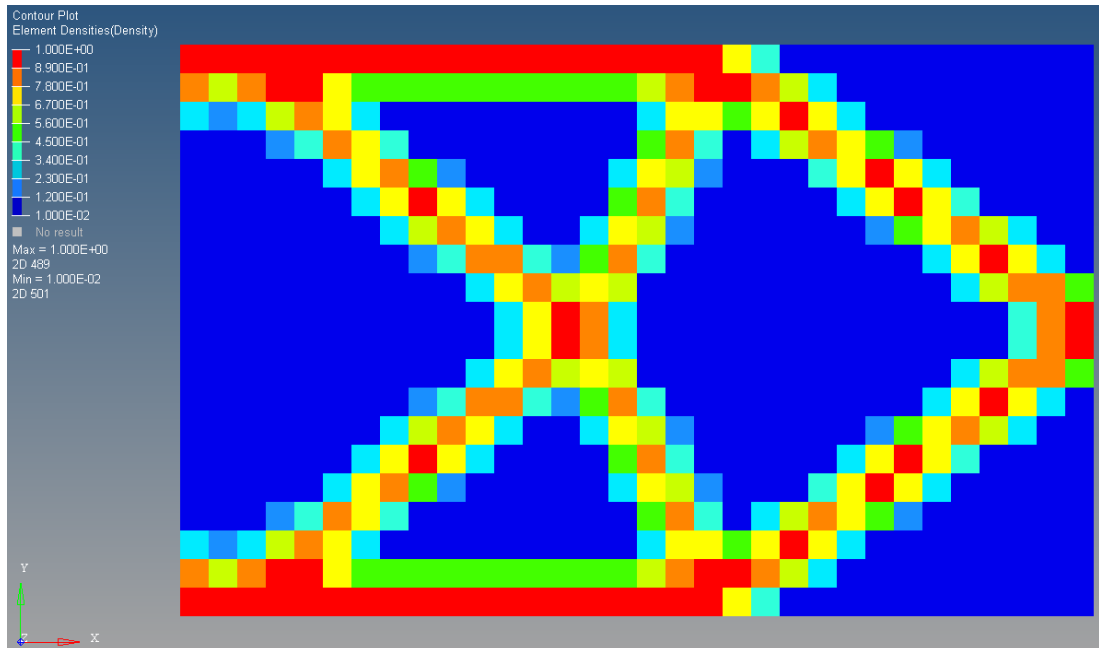
후처리 [1]



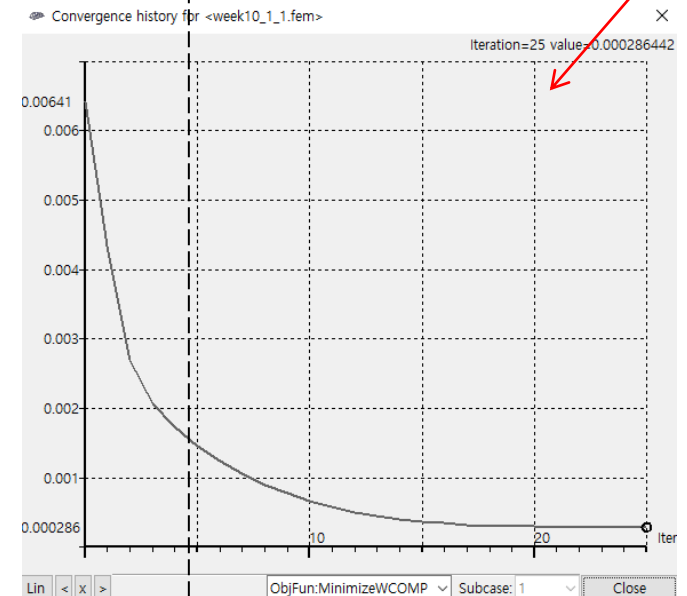
1 Analysis > optistruct

2 Iteration > 마지막 Iteration 선택

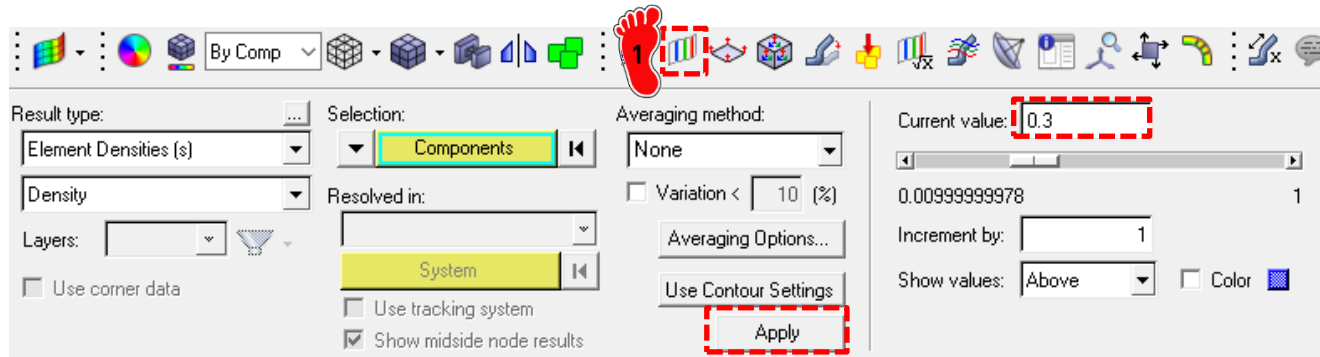
재료 밀도가 1에 가까울수록 중요한 파트라고 볼 수 있음



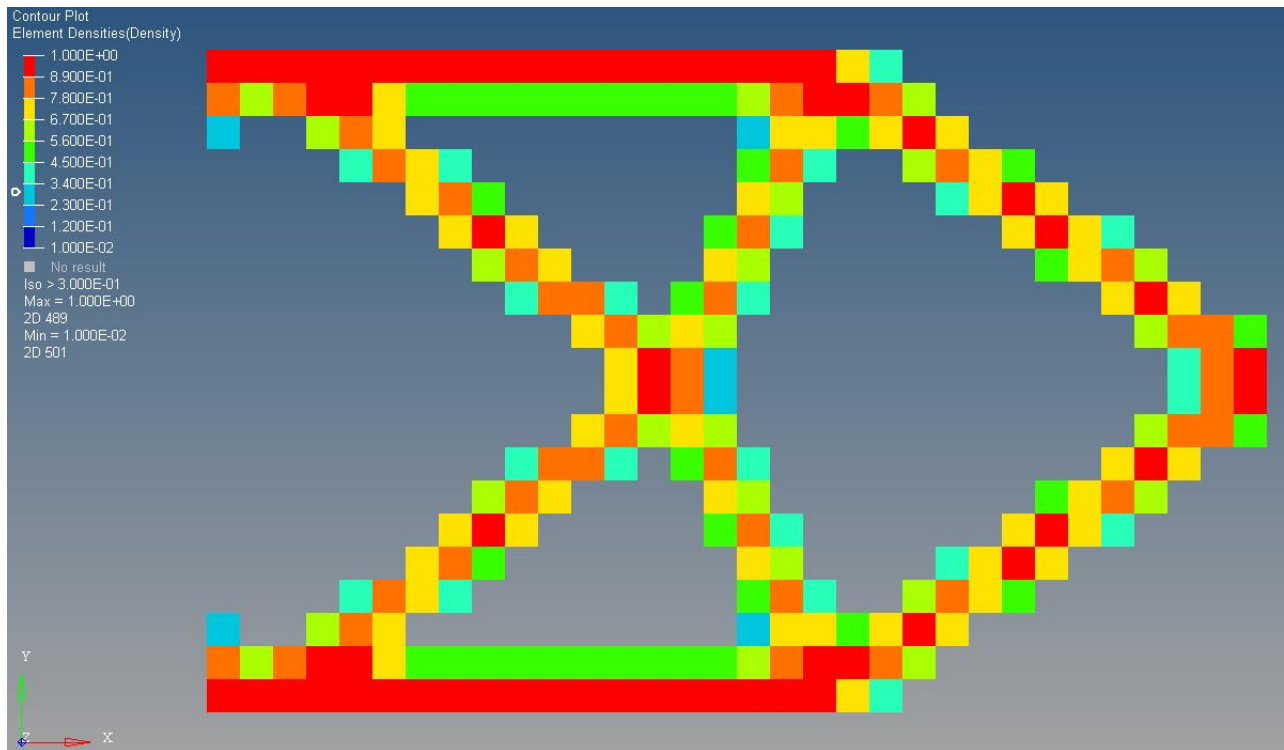
Optimization summary:



후처리 [2]

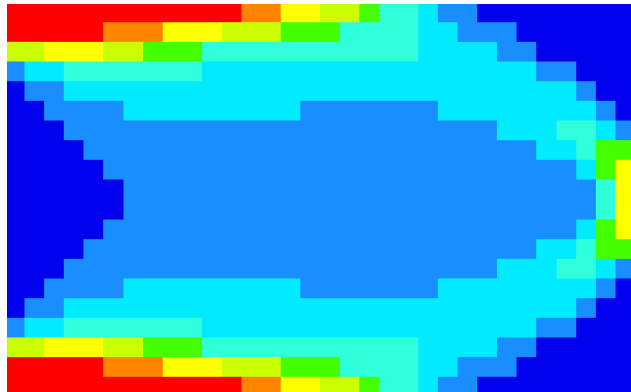


Iso
 Current value > 0.3
 Apply

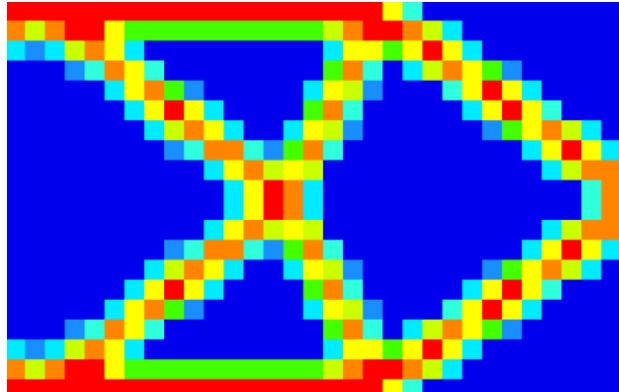


후처리 [2]

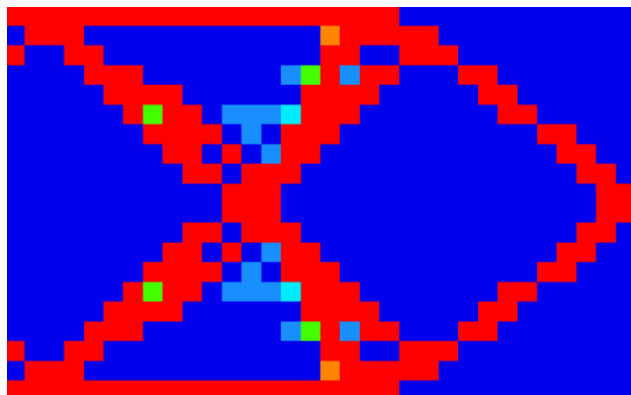
DISCRETE: 0



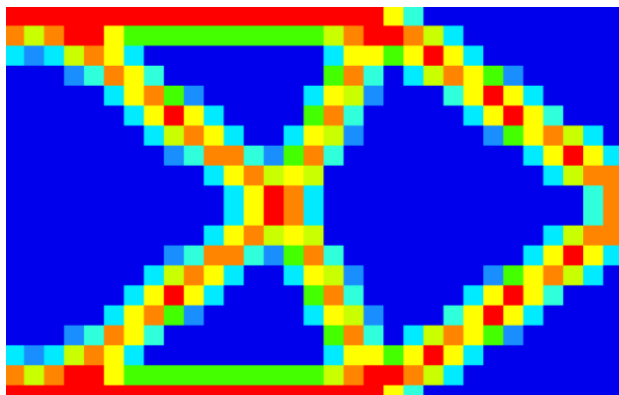
DISCRETE: 3



CHECKER: 0

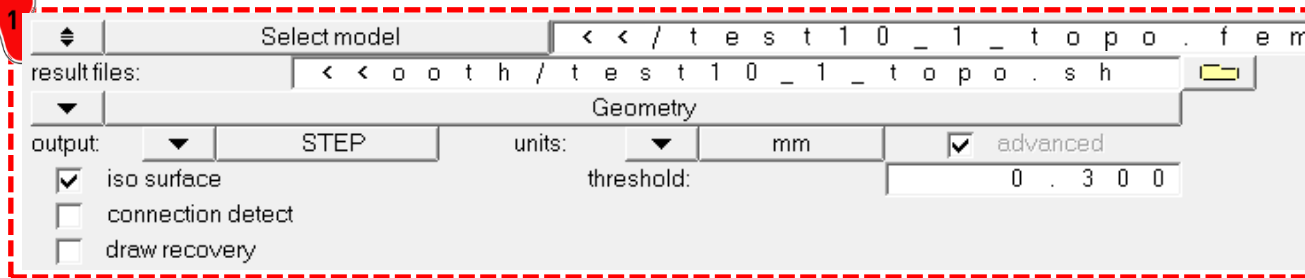


CHECKER: 1

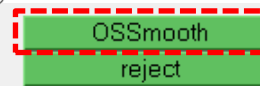


DISCRETE, CHECKER 옵션
에 따른 결과 차이 확인

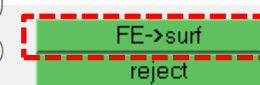
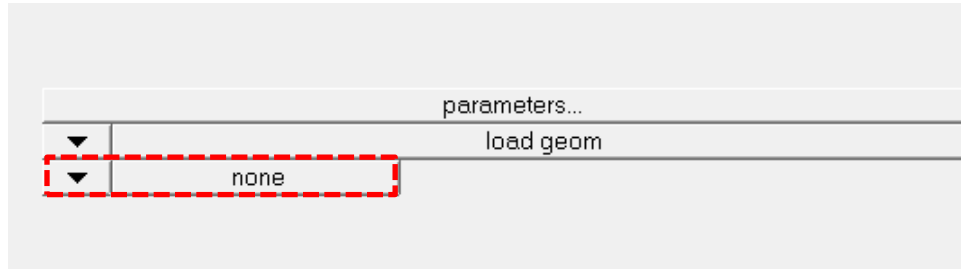
후처리 [3] EXPORT CAD FILE



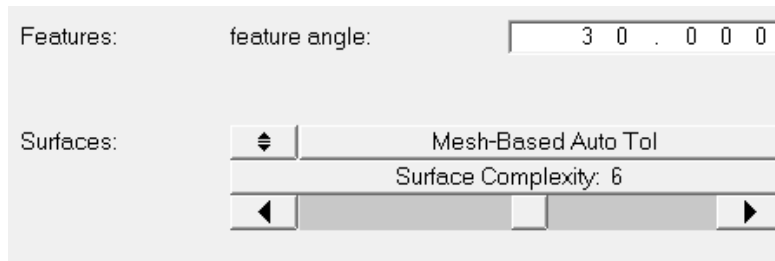
Post > OSSmooth >
Select model >
.fem .sh 선택 >
Geometry > STEP >
threshold: 0.3 >
Check iso surface



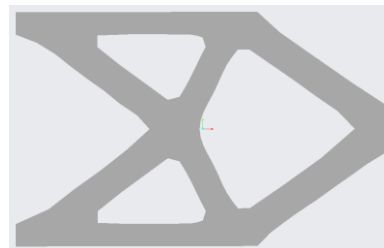
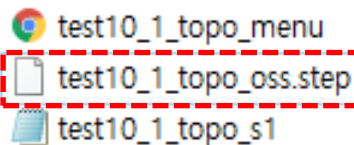
None 선택 > OSSmooth



FE->surf 클릭 > save&exit



생성된 step 파일 확인



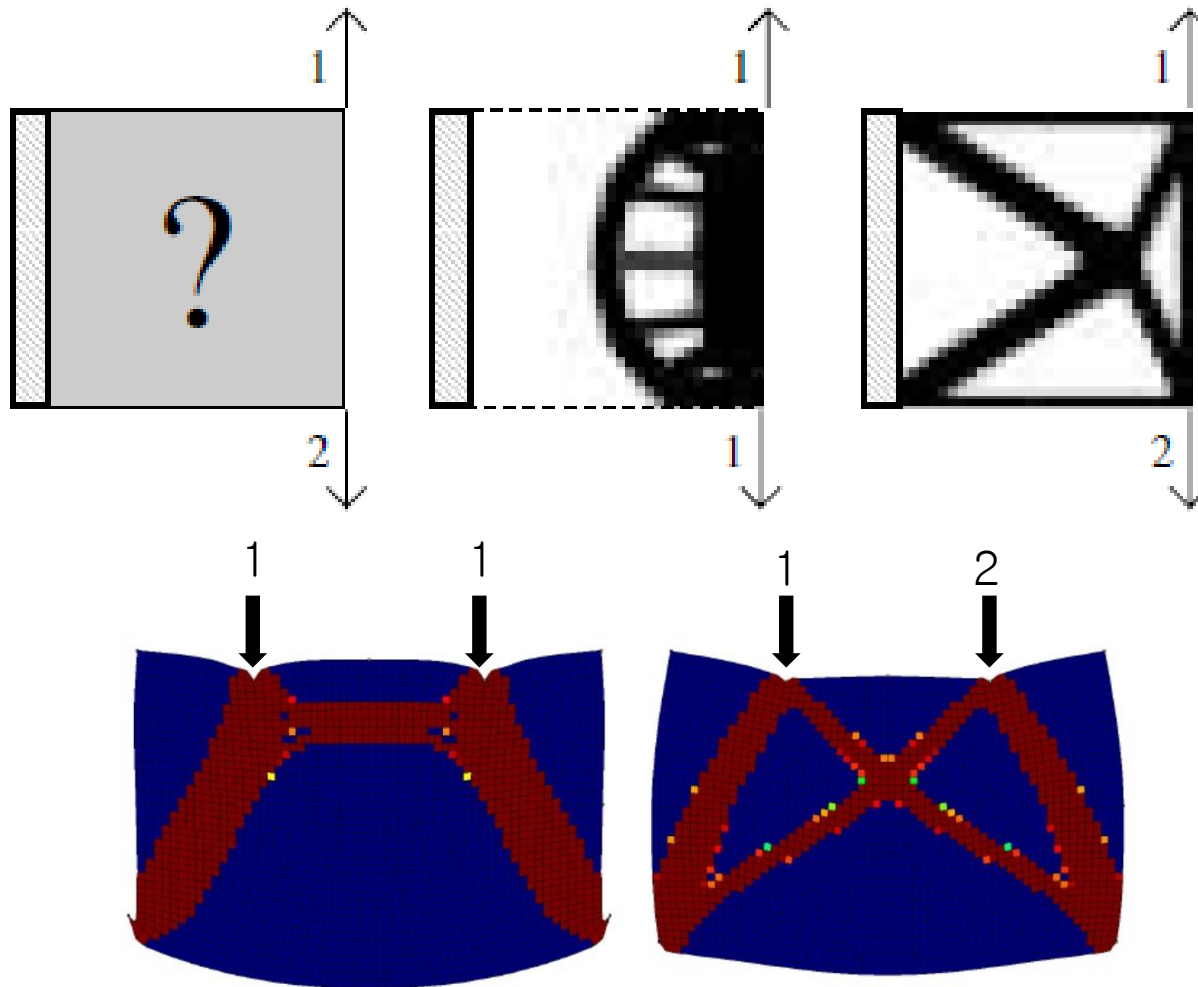
2D STRUCTURE (다중 하중)

목적함수: 컴플라이언스 최소화
구속조건: 부피율



다중 하중 조건

- Combined load vs. Multiple loads



2001, O. Sigmund, "A 99 line topology optimization code written in Matlab", *Struct. Multidisc. Optim.*, Vol. 21

2008, F. Wein, "Topolgy Optimization Using the SIMP Method", Presentation at LSE

구속조건 및 하중조건 설정

1 고정구속

2 load collectors 생성

2 Load Collectors (3)

Collector	Type	1	2
SPC	Support	1	0
load	Load	2	0

F1

F2

123456

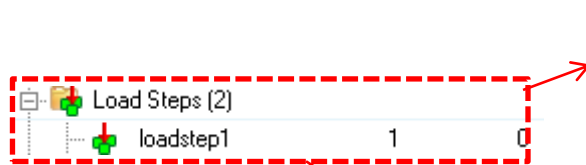
FOREBOD 500.500

FOREBOD 500.500

create update nodes global system equation= 1 / 2 y-axis

create update nodes global system equation= - 1 / 2 y-axis

구속조건 및 하중조건 설정



Analysis type	Linear Static
SPC	(1) SPC
LOAD	(2) load

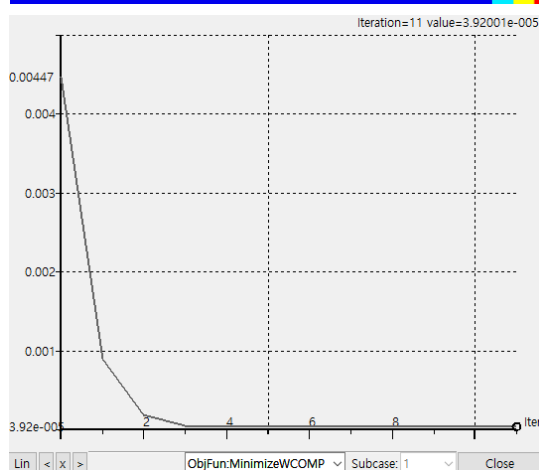
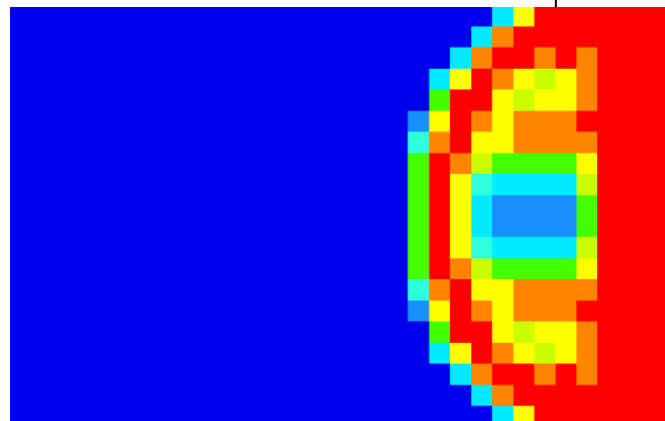
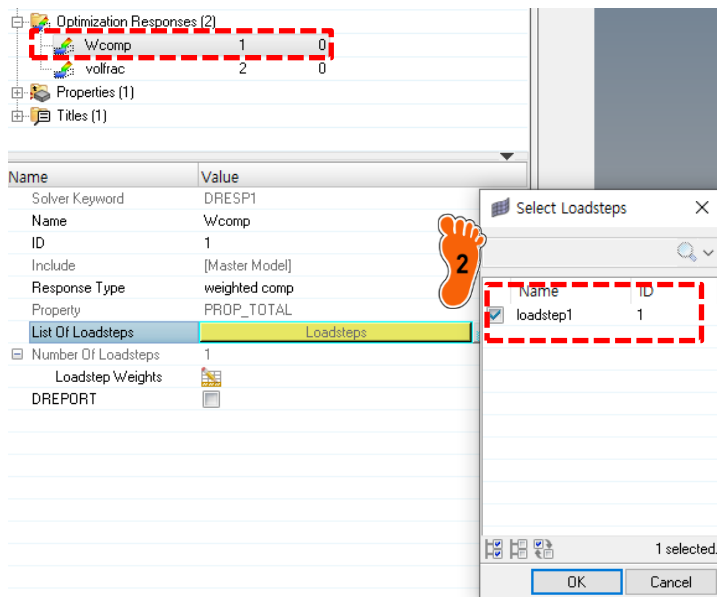


load step 생성



Loadstep1 check

optimization



구속조건 및 하중조건 설정

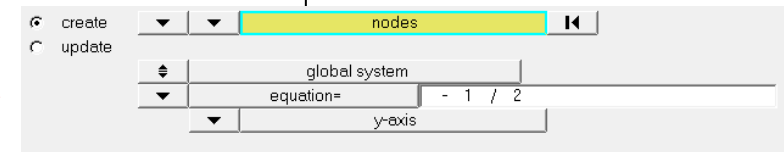
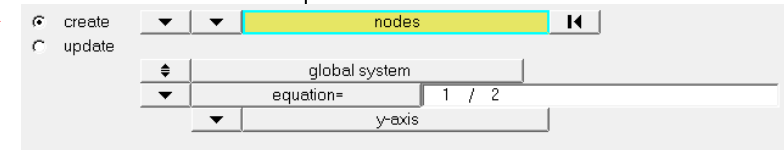
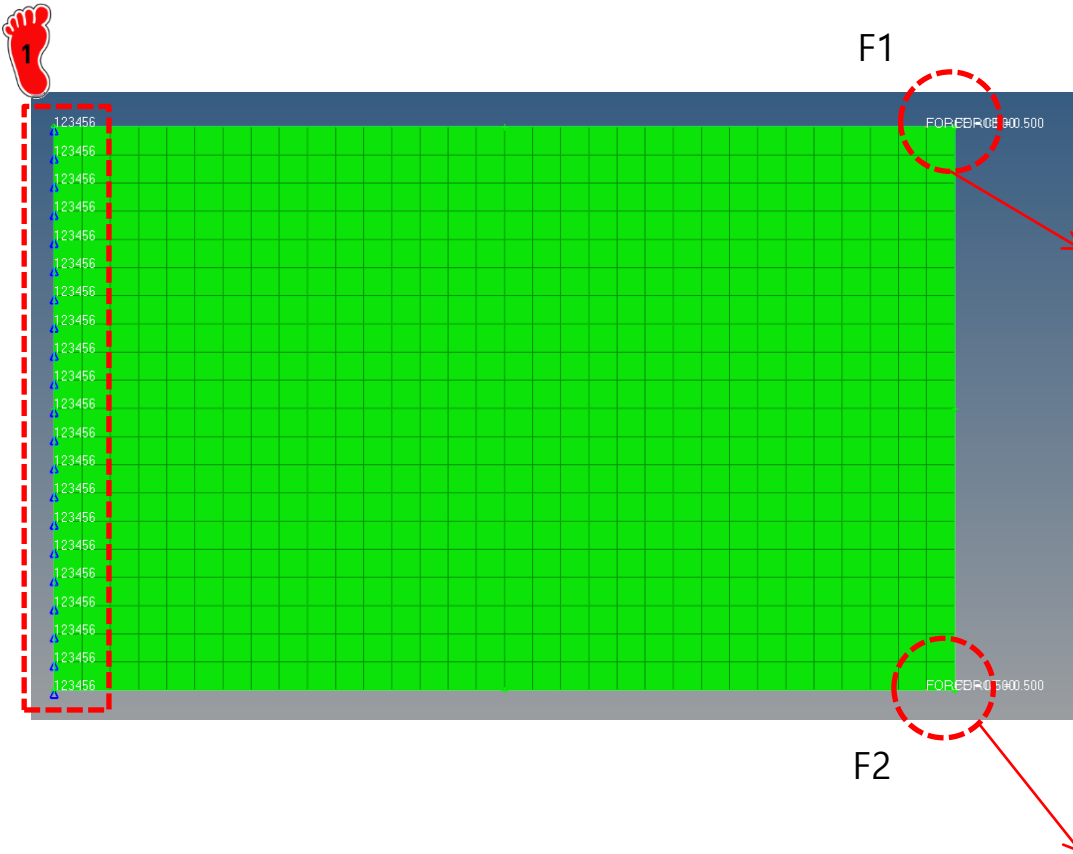
1

2

Load Collectors (3)			
SPC	1		0
load	2		0
load2	3		0

1 고정구속

2 두개의 load collectors 생성
각 각 forces 생성



구속조건 및 하중조건 설정



Load Steps (2)		
loadstep1	1	0
loadstep2	2	0

Analysis type	
SPC	Linear Static
LOAD	(1) SPC
	(2) load



두개의 load step 생성



Loadstep1 check

Analysis type	
SPC	Linear Static
	(1) SPC
LOAD	(3) load2

Optimization Responses (2)

Wcomp	1	0
volfrac	2	0

Properties (1)

Titles (1)

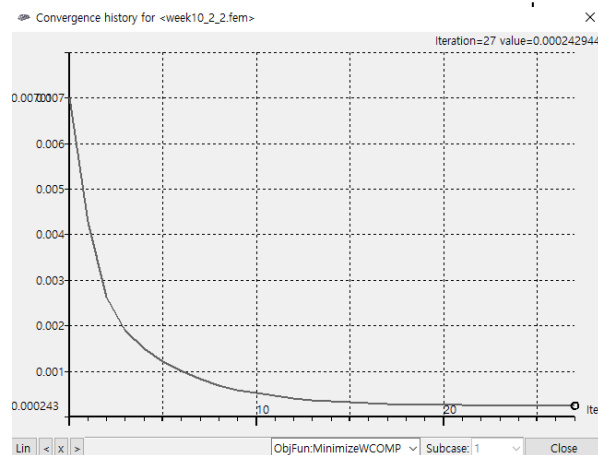
Name	Value
Solver Keyword	DRESP1
Name	Wcomp
ID	1
Include	[Master Model]
Response Type	weighted comp
Property	PROP_TOTAL
List Of Loadsteps	Loadsteps
Number Of Loadsteps	2
Loadstep Weights	
DREPORT	

Select Loadsteps

Name	ID
☒ loadstep1	1
☐ loadstep2	2

1 selected.

OK Cancel



구속조건 및 하중조건 설정



Load Steps (2)		
loadstep1	1	0
loadstep2	2	0

Analysis type	
SPC	(1) SPC
LOAD	(2) load



두개의 load step 생성



Loadstep2 check

Optimization Responses (2)

Wcomp	1	0
vofrac	2	0

Properties (1)

Titles (1)

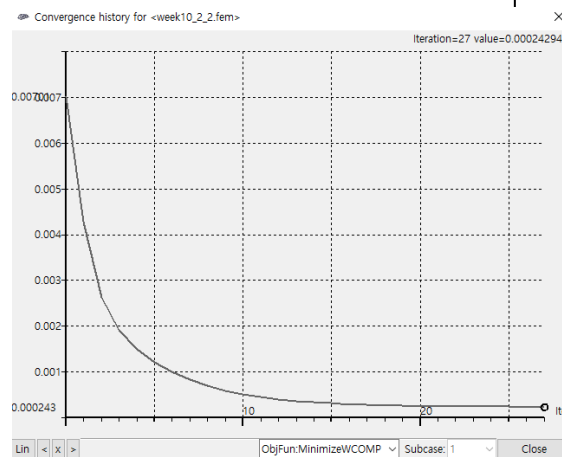
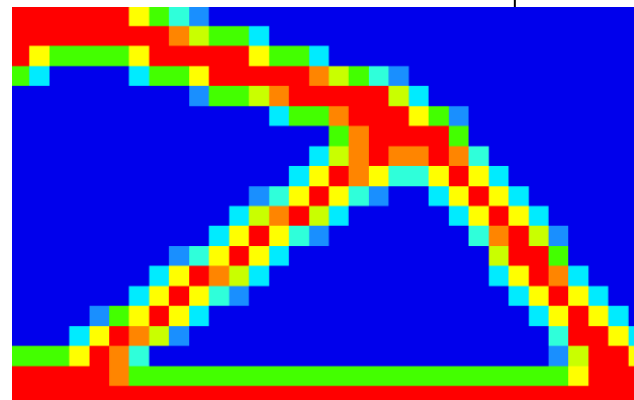
Name	Value
Solver Keyword	DRESP1
Name	Wcomp
ID	1
Include	[Master Model]
Response Type	weighted comp
Property	PROP_TOTAL
List Of Loadsteps	Loadsteps
Number Of Loadsteps	2
Loadstep Weights	
DREPORT	

Select Loadsteps

Name	ID
loadstep1	1
loadstep2	2

1 selected.

OK Cancel



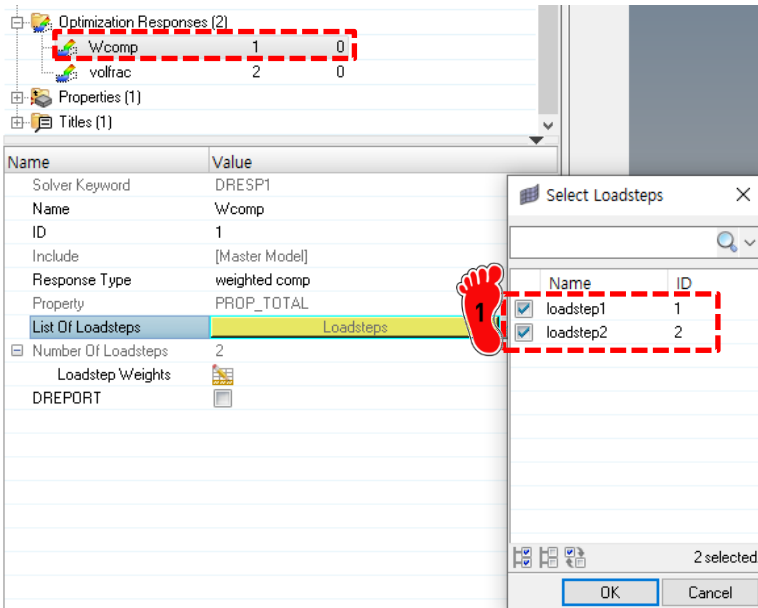
구속조건 및 하중조건 설정



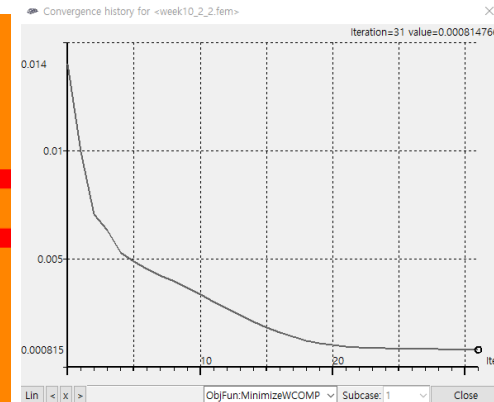
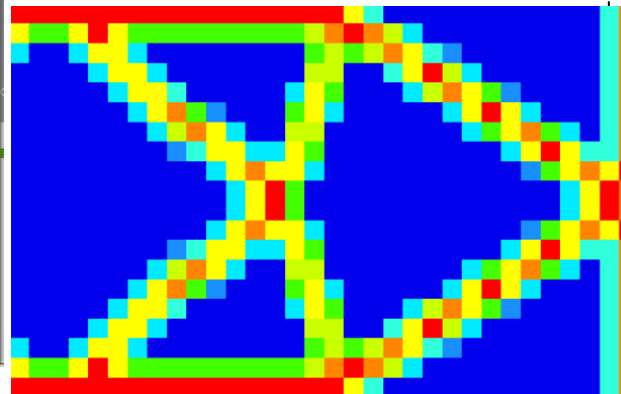
Loadstep1,2 check
> optistruct



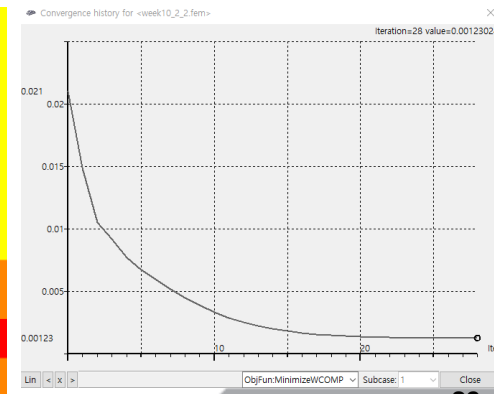
아래쪽 load 크기 2로 변경
> optistruct



Multiple loads (F1:F2=1:1)



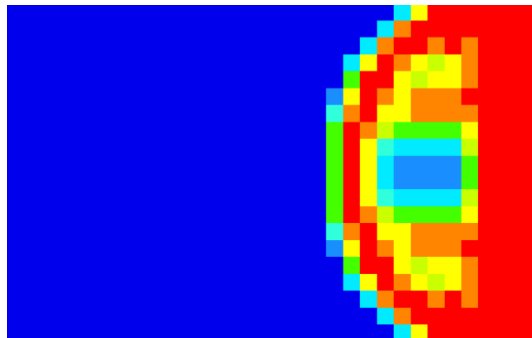
Multiple loads (F1:F2=1:2)



Solver Keyword	DRESP1
Name	Wcomp
ID	2
Include	[Master Model]
Response Type	weighted comp
Property	PROP_TOTAL
List Of Loadsteps	2 Loadsteps
Number Of Loadsteps	2
Loadstep Weights	
DREPORT	
Number Of Loadsteps	
Loadstep ID	Weight
1 2	2
2 1	1

최적화 결과

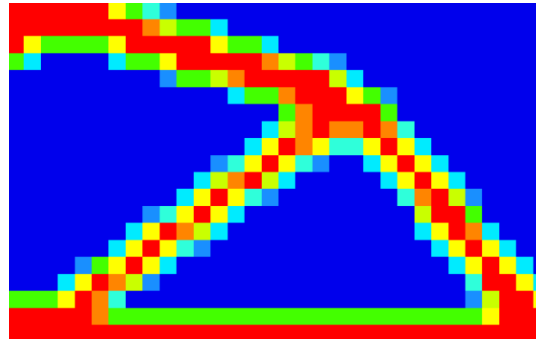
Combined load



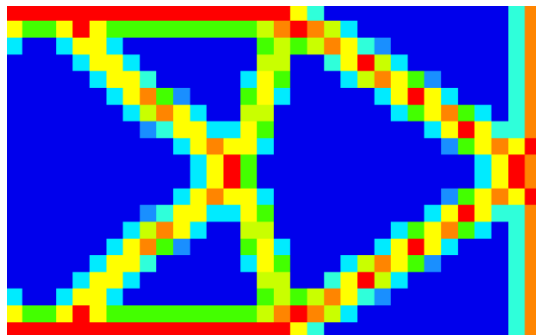
Single load 1



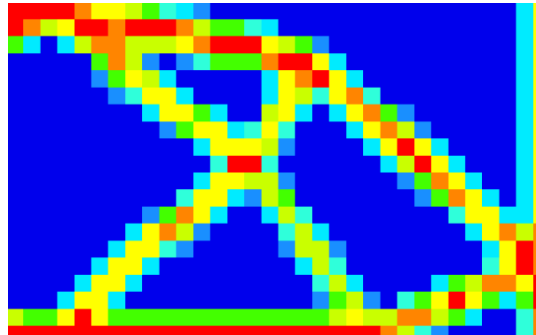
Single load 2



Multiple loads (F1:F2=1:1)



Multiple loads (F1:F2=1:2)



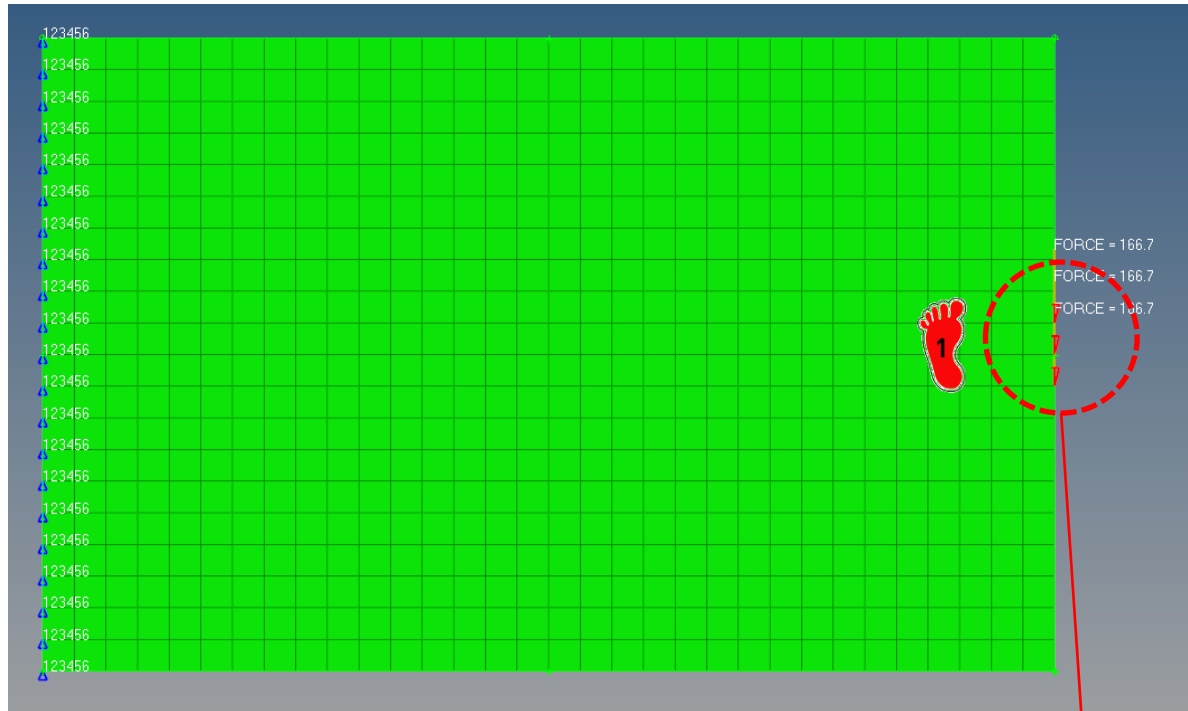
Combined load의 경우 하중을 동시에 적용한 경우에 대해 결과가 나오고, Multiple loads의 경우 각각의 하중 모두에 대한 최적화 결과가 나타나게 됨

2D STRUCTURE (단일 하중)

목적함수: 부피 최소화
구속조건: 변위



하중조건 변경



☒ create ☐ update

nodes

global system

equation= - 5 0 0 / 3

y-axis

1 중앙 3개 노드에 하중 크기
 -500/3 N 으로 변경

DESIGN VARIABLE SETTING

→ **Design variable**

→ **Responses**

→ **Objective**

→ **Dconstraints**

→ **Opti control**



Analysis > optimization >
topology

create



RESPONSE SETTING (1)

→ Design variable

→ **Responses**

→ Objective

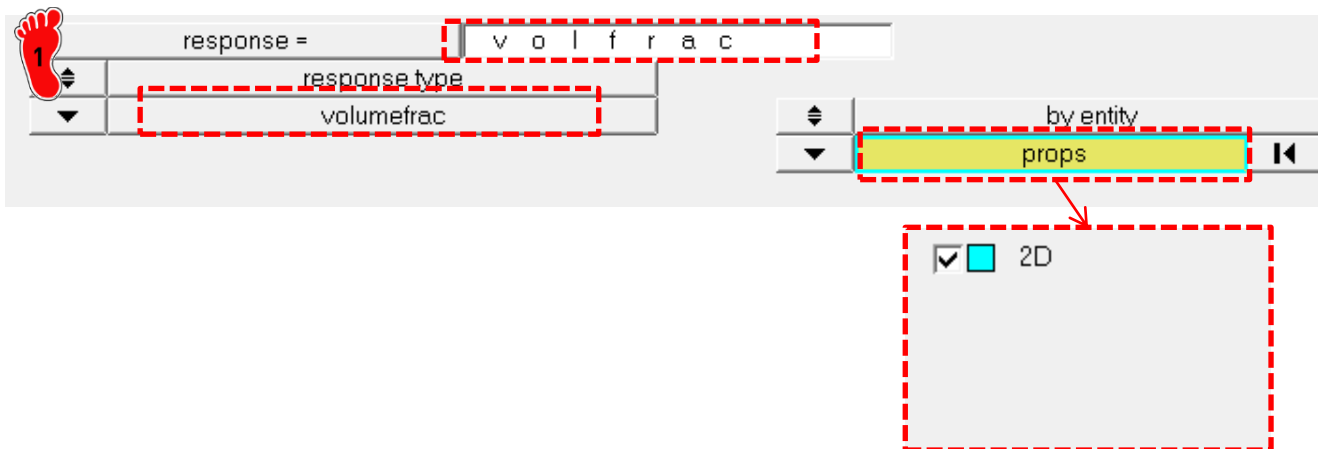
→ Dconstraints

→ Opti control



Analysis > optimization > responses

volumefrac > create



RESPONSE SETTING (2)

→ Design variable

→ **Responses**

→ Objective

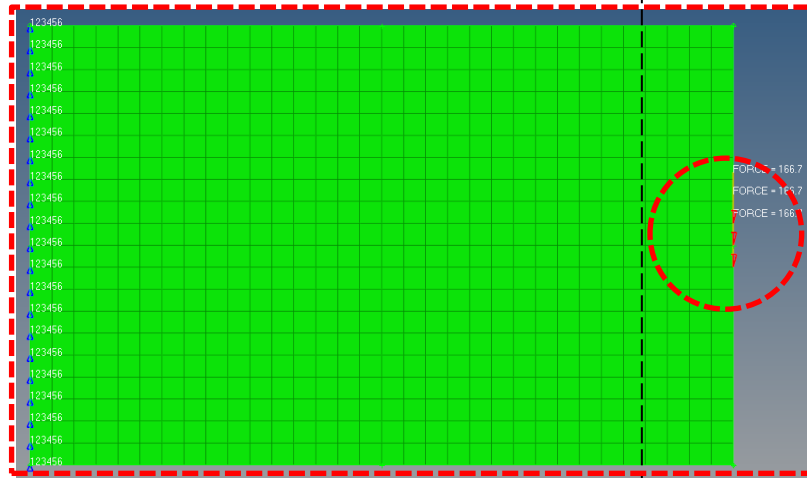
→ Dconstraints

→ Opti control



Analysis > optimization > responses

Y방향(dof2) 변위 > create



response =

d i s p

response type

static displacement

nodes

numbers

no regionid

☐ dof1

☒ dof2

☐ dof3

☐ total disp

☐ dof4

☐ dof5

☐ dof6

☐ total rotation

OBJECTIVE SETTING

→ Design variable

→ Responses

→ **Objective**

→ Dconstraints

→ Opti control



Analysis > optimization >
objective

create



▼ min

response = volfrac

CONSTRAINTS SETTING

→ Design variable

→ Responses

→ Objective

→ **Dconstraints**

→ Opti control



Analysis > optimization >
dconstraints

Y-displacement $\geq$ -0.1mm

create



constraint =	d i s p
lower bound =	- 0 . 1 0 0
upper bound =	1 . 0 0 0 e + 2 0

response =	d i s p
loadsteps	1

☒ loadstep1

CONTROL SETTING



Analysis > optimization >
opti control

→ Design variable

→ Responses

→ Objective

→ Dconstraints

→ Opti control

DESMAX: Maximum number of design iterations

OBJTOL: 0.5% change in the objective function



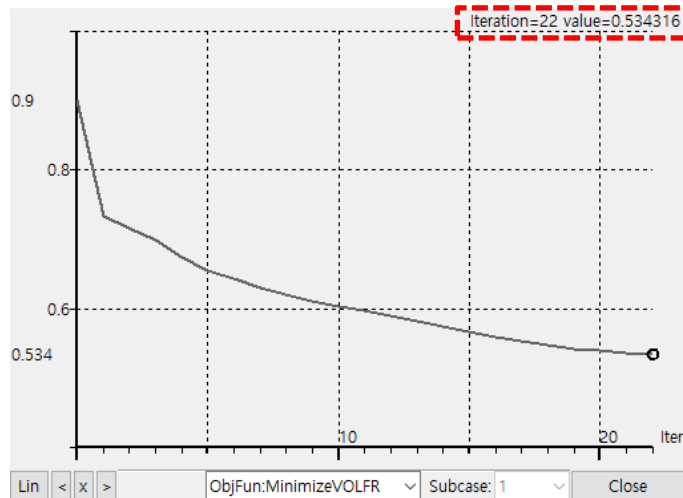
☒	DESMAX=	50	☒	OBJTOL=	0.005
☐	MINDIM=	0.000	☐	DELSIZ=	0.500
☐	MATINIT=	0.600	☐	DELSHP=	0.200
☐	MINDENS=	0.010	☐	DELTOP=	0.500
☒	DISCRETE=	3.000	☐	GBUCK=	0
☒	CHECKER=	1	☐	MAXBUCK=	10
☐	MMCHECK=	0	☐	DISCRT1D=	1.000

DISCRETE: Higher values decrease the number of elements that remain between 0 and 1.

CHECKER: Checkerboard control option. (0 = no checkerboard control)

후처리 (1)

Convergence history for <disp.fem>



Graph click

목적함수 확인 > 53.4 %



Displacement(y) 확인
(최종 Iteration)



Contour Plot
Element Densities(Density)

1.000E+00
8.900E-01
7.800E-01
6.700E-01
5.600E-01
4.500E-01
3.400E-01
2.300E-01
1.200E-01
1.000E-02

No result
Max = 1.000E+00
2D 481
Min = 1.000E-02
2D 504

Contour Plot
Displacement(Y)
Analysis system

No result
Max = 0.000E+00
Grids 53
Min = -9.992E-02
Grids 11

Y
X

Y
X



Contour Plot
Displacement(Y)
Analysis system

0.000E+00
-1.110E-02
-2.220E-02
-3.331E-02
-4.441E-02
-5.551E-02
-6.661E-02
-7.772E-02
-8.882E-02
-9.992E-02

No result

Max = 0.000E+00
Grids 53
Min = -9.992E-02
Grids 11

후처리 (2)



변위 조건 바뀌가면서 확인

Entities	ID	Include
Assembly Hierarchy		
Components (1)		
Design Variables (1)		
dv1	1	0
Load Collectors (2)		
SPC	1	0
load	2	0
Load Steps (1)		
loadstep1	1	0
Materials (1)		
Objectives (1)		
objective	1	0
Optimization Constraints (1)		
disp	1	0
Optimization Controls (1)		
optistruct_opticontrol	1	0
Optimization Responses (2)		
volfrac	2	0
disp	3	0
Properties (1)		
Titles (1)		

Name	Value
Solver Keyword	DCONSTR
Name	disp
ID	1
Include	[Master Model]
Lower Bound	-0.1
Upper Bound	
Response	(3) disp
List of Loadsteps	1 Loadsteps
PROB	

Solver Keyword	DCONSTR
Name	disp
ID	1
Include	[Master Model]
Lower Bound	-0.2
Upper Bound	
Response	(3) disp
List of Loadsteps	1 Loadsteps
PROB	

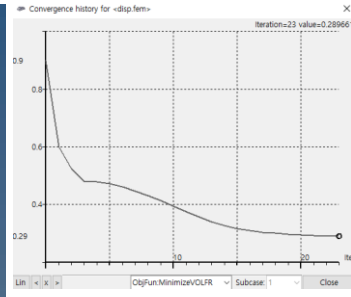
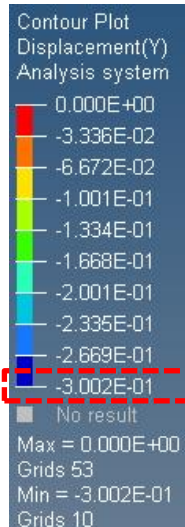
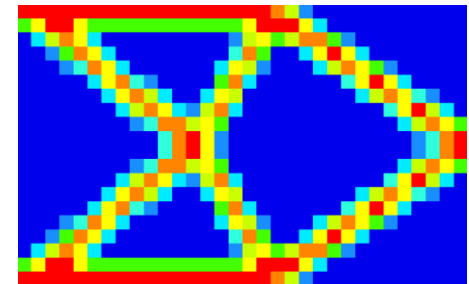
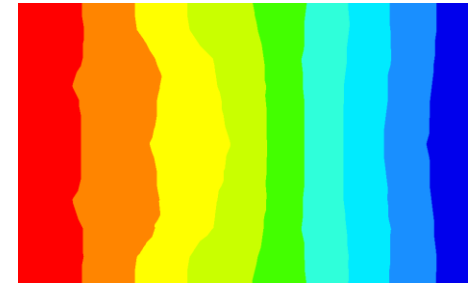
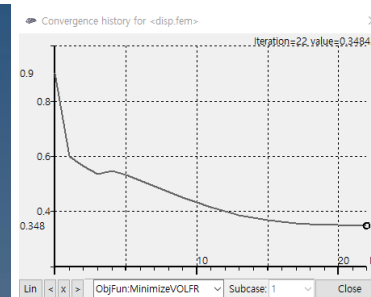
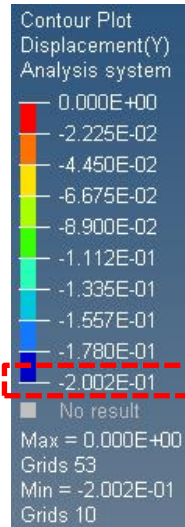
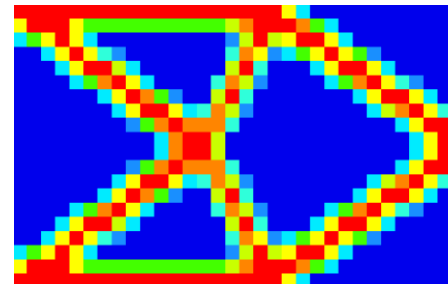
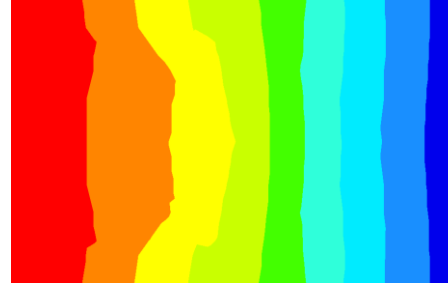
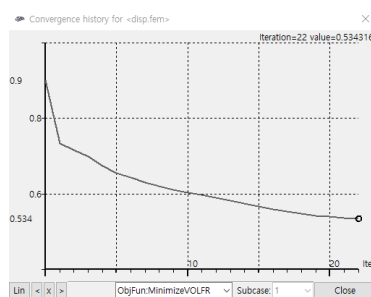
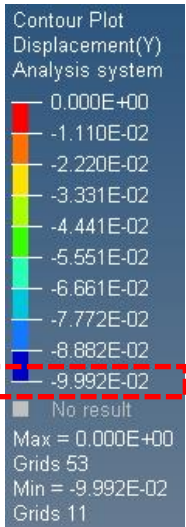
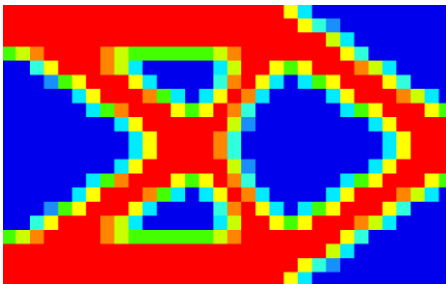
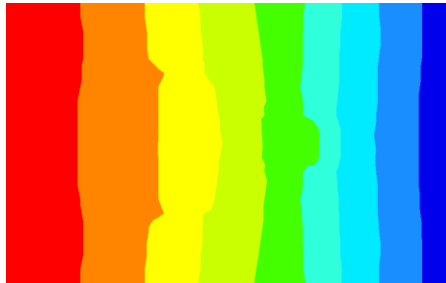
Name	Value
Solver Keyword	DCONSTR
Name	disp
ID	1
Include	[Master Model]
Lower Bound	-0.3
Upper Bound	
Response	(3) disp
List of Loadsteps	1 Loadsteps
PROB	

후처리 (4)

변위 제약조건 0.1
→ 부피율: 53.4%

변위 제약조건 0.2
→ 부피율: 34.8%

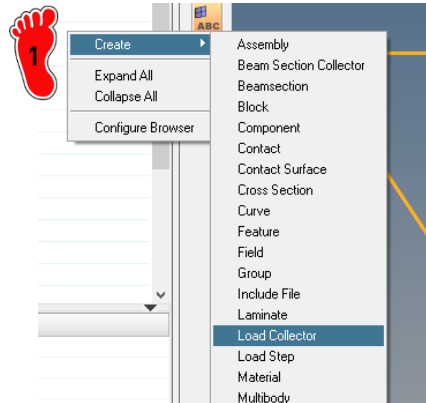
변위 제약조건 0.3
→ 부피율: 28.9%



2D STRUCTURE

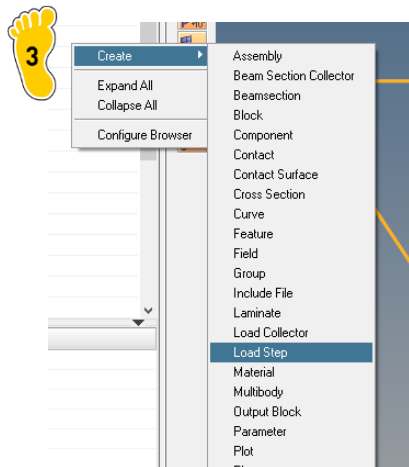
목적함수: 고유주파수 최대화
구속조건: 부피율

구속조건 및 하중조건 설정



2

Name	Value
Solver Keyword	EIGRL
Name	EIGRL
ID	2
Color	
Include	[Master Model]
Card Image	EIGRL
User Comments	Hide In Menu/Export
V1	
V2	
ND	20
MSGVL	
MAXSET	
SHFSCL	
NORM	MASS



4

Name	Value
Solver Keyword	SUBCASE
Name	loadstep1
ID	1
Include	[Master Model]
User Comments	Hide In Menu/Export
Subcase Definition	
Analysis type	Normal modes
SPC	(1) spc
MPC	<Unspecified>
METHOD (STRUCT)	(2) EIGRL
METHOD (FLUID)	<Unspecified>
STATSUB (PRELOAD)	<Unspecified>

1 Create > Load Collector

2 Name > EIGRL
Card Image > EIGRL
ND > 20

3 Create > Load Step

4 Analysis type
> Normal Modes
SPC > spc
METHOD(STRUCT)
> EIGRL

DESIGN VARIABLE SETTING

→ **Design variable**

→ **Responses**

→ **Objective**

→ **Dconstraints**

→ **Opti control**



Analysis > optimization >
topology

create



RESPONSE SETTING (1)

→ Design variable

→ **Responses**

→ Objective

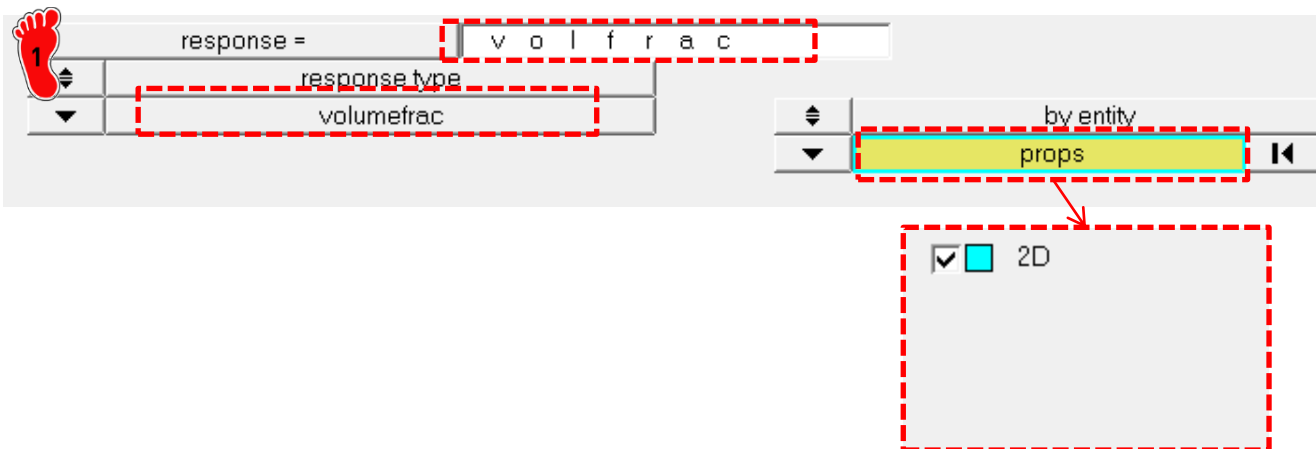
→ Dconstraints

→ Opti control



Analysis > optimization > responses

volumefrac > create



RESPONSE SETTING (2)

→ Design variable

→ **Responses**

→ Objective

→ Dconstraints

→ Opti control



Analysis > optimization > responses

Frequency > create
Mode number > 1
Loadsteps check (X)



response =

response type
frequency

Mode Number:

☐ FRF based mode identification

no regionid

OBJECTIVE SETTING

→ Design variable

→ Responses

→ **Objective**

→ Dconstraints

→ Opti control



Analysis > optimization >
objective

create



max

response = f r e q

loadstep

loadstep1

CONSTRAINTS SETTING

→ Design variable

→ Responses

→ Objective

→ **Dconstraints**

→ Opti control



Analysis > optimization >
dconstraints

volfrac ≤ 70%

create



constraint =

volfrac

lower bound =

- 1 . 0 0 0 e + 2 0

upper bound =

0 . 7 0 0

response =

volfrac

CONTROL SETTING



Analysis > optimization >
opti control

→ Design variable

→ Responses

→ Objective

→ Dconstraints

→ Opti control

DESMAX: Maximum number of design iterations

OBJTOL: 0.5% change in the objective function

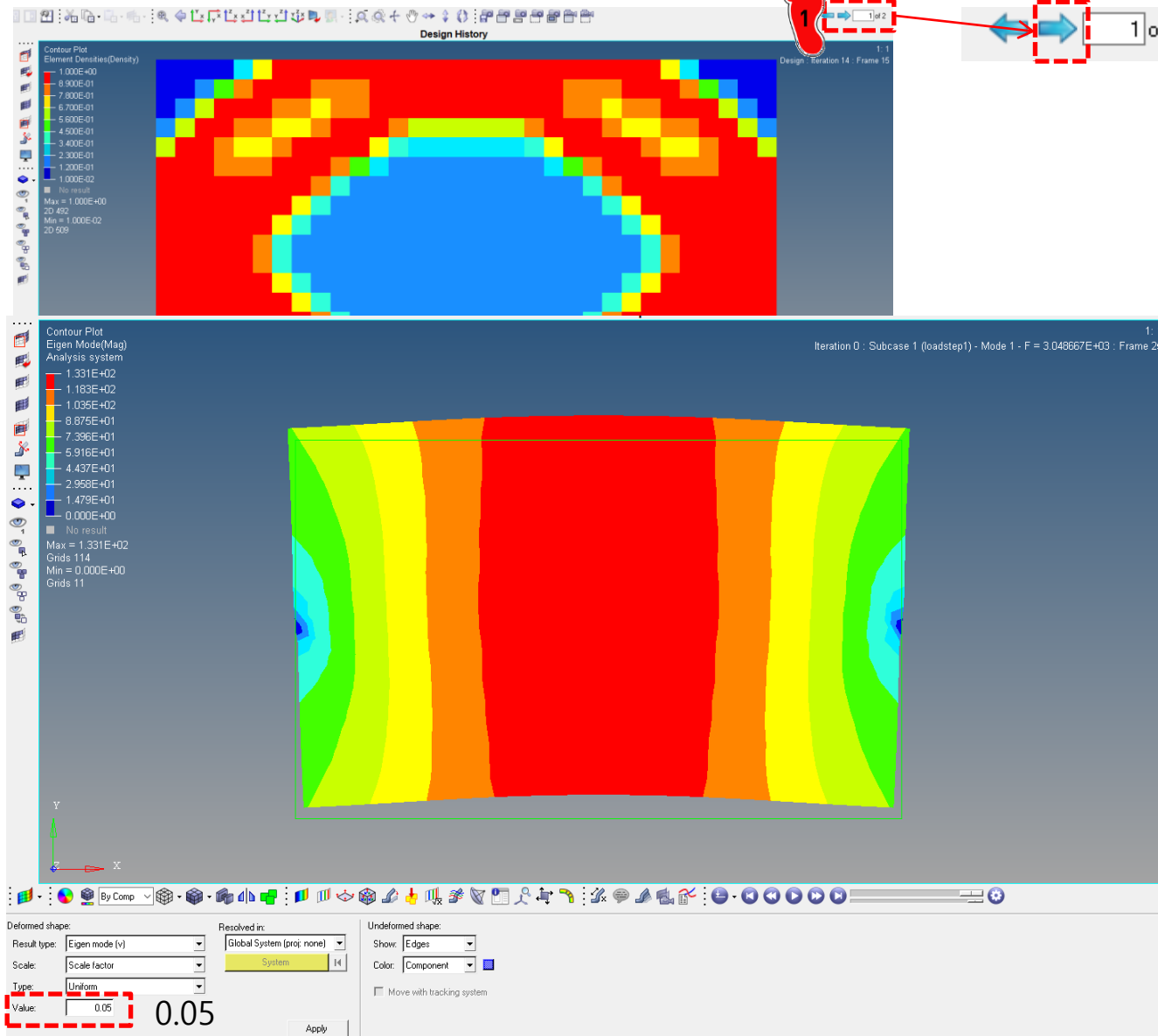


☒	DESMAX=	50	☒	OBJTOL=	0.005
☐	MINDIM=	0.000	☐	DELSIZ=	0.500
☐	MATINIT=	0.600	☐	DELSHP=	0.200
☐	MINDENS=	0.010	☐	DELTOP=	0.500
☒	DISCRETE=	3.000	☐	GBUCK=	0
☒	CHECKER=	1	☐	MAXBUCK=	10
☐	MMCHECK=	0	☐	DISCRT1D=	1.000

DISCRETE: Higher values decrease the number of elements that remain between 0 and 1.

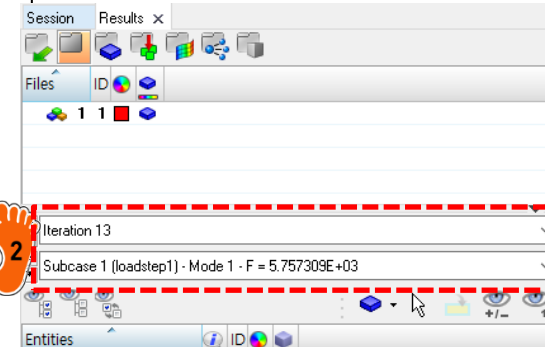
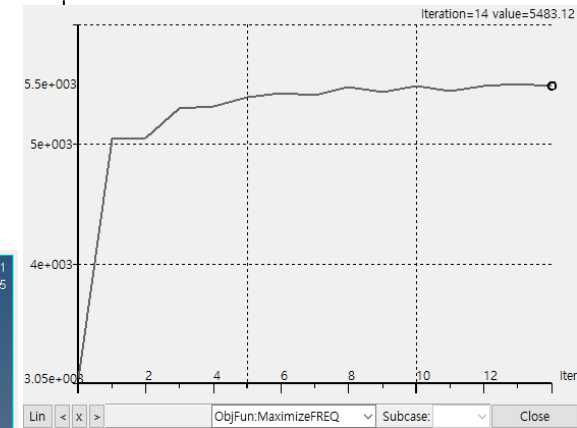
CHECKER: Checkerboard control option. (0 = no checkerboard control)

후처리



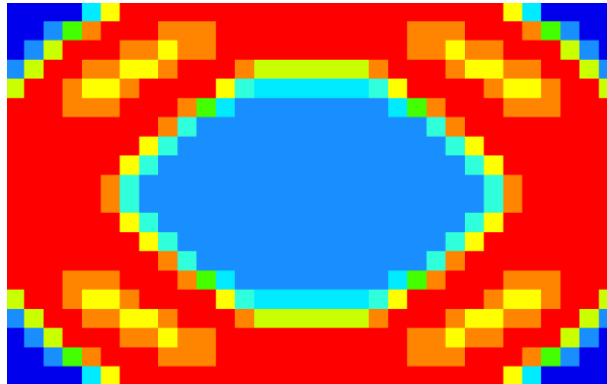
1 Eigen Mode 확인

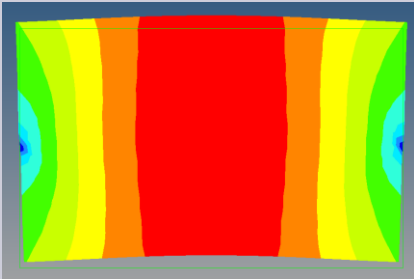
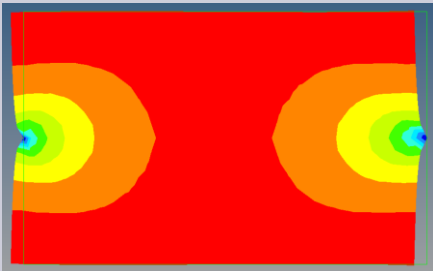
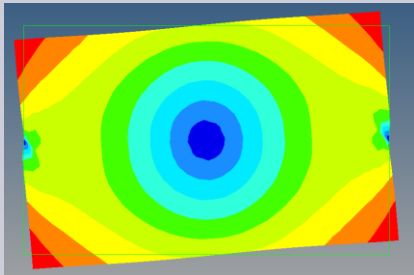
Create



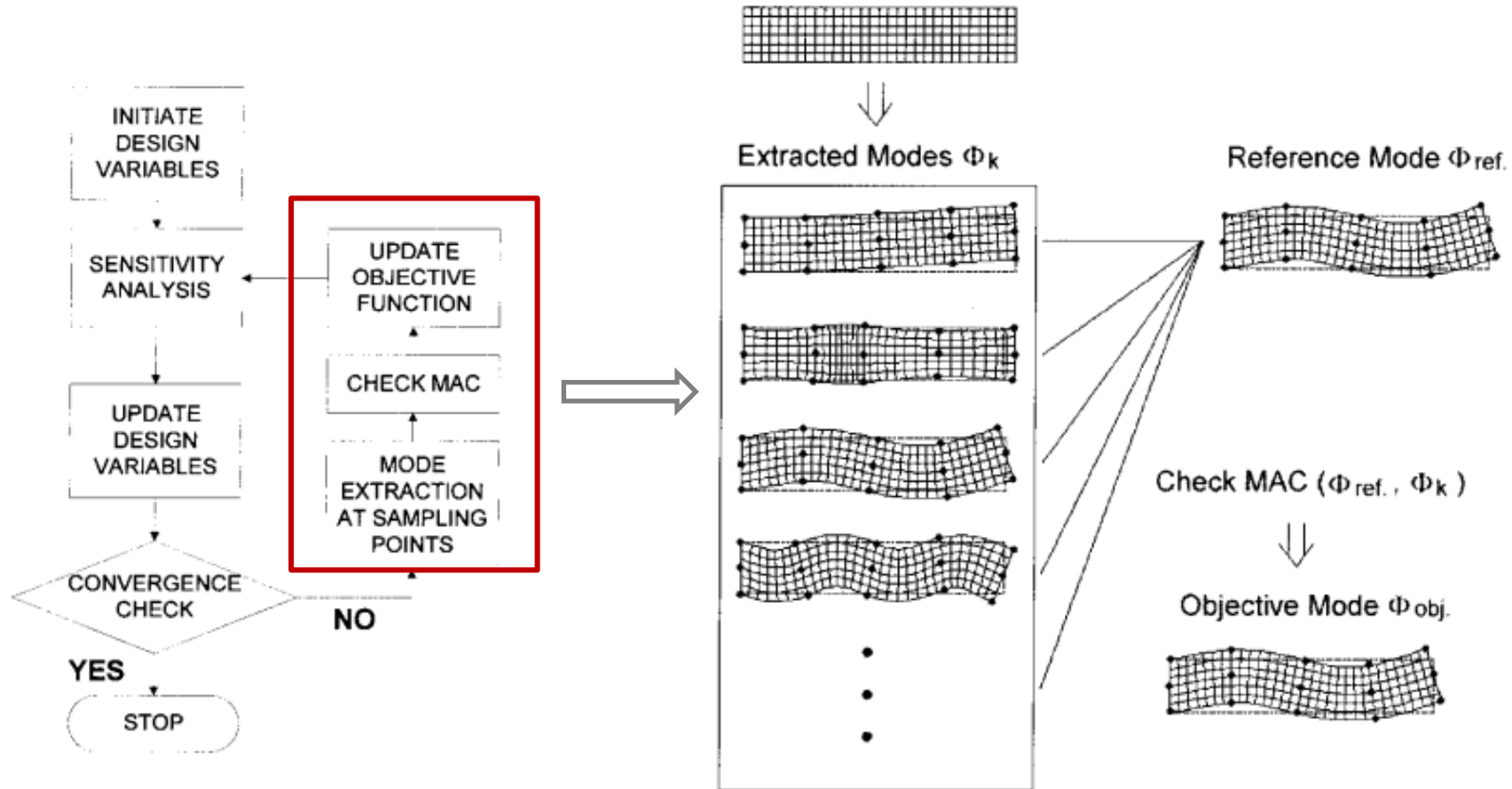
후처리

최적화 결과



모드 차수	1차	2차	3차
변형 형상			
고유주파수	3048	3699	5612

MODE TRACKING



$$MAC(\Phi_a, \Phi_b) = \frac{|\Phi_a^T \Phi_b|^2}{(\Phi_a^T \Phi_a)(\Phi_b^T \Phi_b)}$$

$$\Phi_{obj} = \Phi_k \text{ such that } \max_k [MAC(\Phi_{ref}, \Phi_k)],$$

$$k = 1, 2, \dots, N_m$$

MODE TRACKING SETTING

response = w f r e q

response type
weighted freq

Mode

1	1 . 0 0 0
2	1 . 0 0 0 e - 2 0
3	1 . 0 0 0 e - 2 0
4	1 . 0 0 0 e - 2 0
5	1 . 0 0 0 e - 2 0
0	0 . 0 0 0

Weight

min response = w f r e q

주파수 최대화 시, weighted freq의 경우 min으로 지정
주파수가 분모에 지정 되어 있음 (1/f)

1 optimization > responses
> weighted freq 선택

2 Mode: 1,2,3,4,5
Weight: mode 1에 1,
이외 1e-20 입력

3 optimization > objective >
min 선택 > wfreq 선택

MODE TRACKING SETTING

1

PARAM 1 0

☒ MODETRAK
MODET_V1 YES

2

☒ TRAKMETH
VALUE 1

VALUE: 0 (default)

$$CORC(\Phi^{(k-1)}, \Phi^{(k)}) = \left(\Phi^{(k-1)} \right)^T \mathbf{M}^{(k)} \Phi^{(k)}$$

VALUE: 1

$$MACSR(\Phi^{(k-1)}, \Phi^{(k)}) = \frac{\left(\Phi^{(k-1)} \right)^T \Phi^{(k)}}{\left| \Phi^{(k-1)} \right| \left| \Phi^{(k)} \right|}$$

VALUE: 2

$$MAC(\Phi^{(k-1)}, \Phi^{(k)}) = \left[\frac{\left(\Phi^{(k-1)} \right)^T \Phi^{(k)}}{\left| \Phi^{(k-1)} \right| \left| \Phi^{(k)} \right|} \right]^2$$

1

PARAM 카드에서
MODETRAK 체크 >
MODET_V1: YES
(mode tracking ON)

2

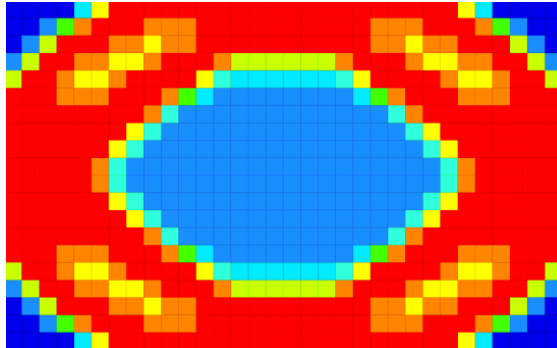
PARAM 카드에서
TRAKMETH 체크 >
VALUE: 1
(MACSR 선택)

RESPONSE 비교

response: **frequency**

response =

response type

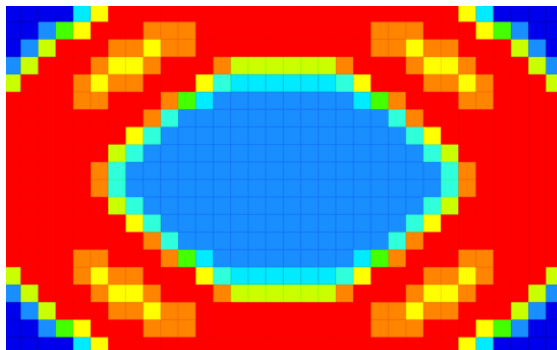


Max freq 1: 5483
 freq 2: 5532
 freq 3: 6088
 freq 4: 8373
 freq 5: 10156

response: **weighted freq**

response =

response type

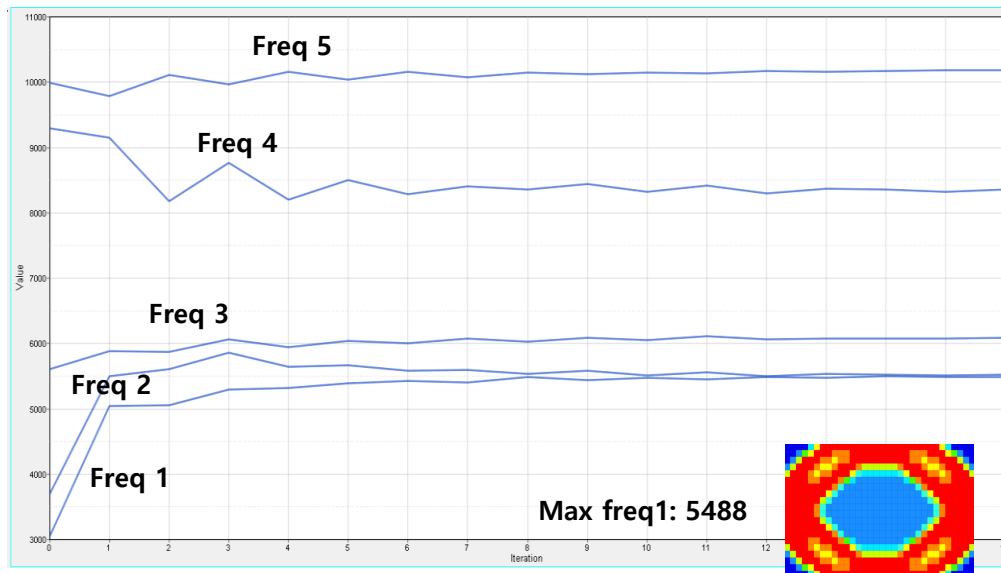


Max freq 1: 5488
 freq 2: 5517
 freq 3: 6091
 freq 4: 8354
 freq 5: 10182

frequency vs. weighted freq
 유사한 결과 도출

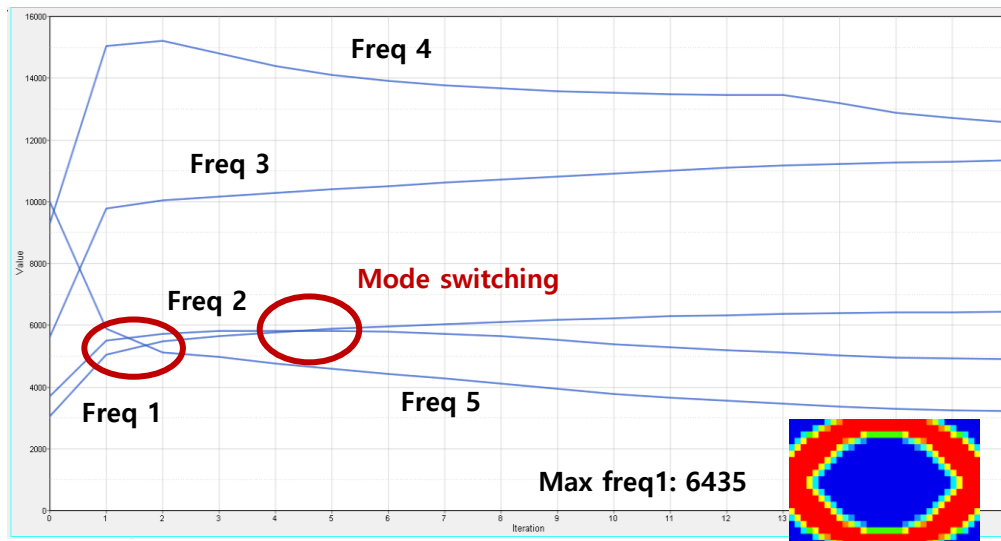
RESULTS

MODETRAK: **OFF**



Mode tracking 'OFF' 결과

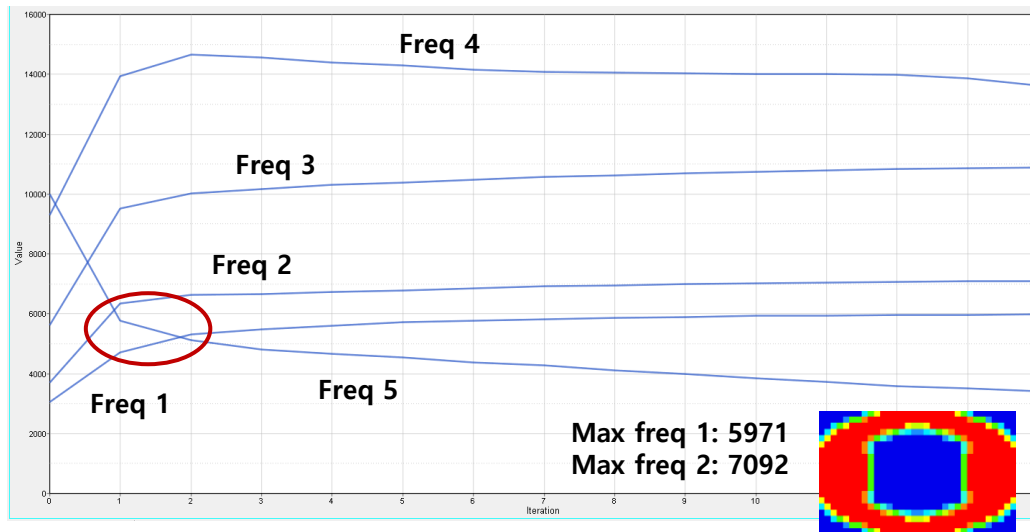
MODETRAK: **ON**, TRAKMETH: **1 (MACSR)**



Mode tracking 'ON'
TRAKMETH '1' 결과

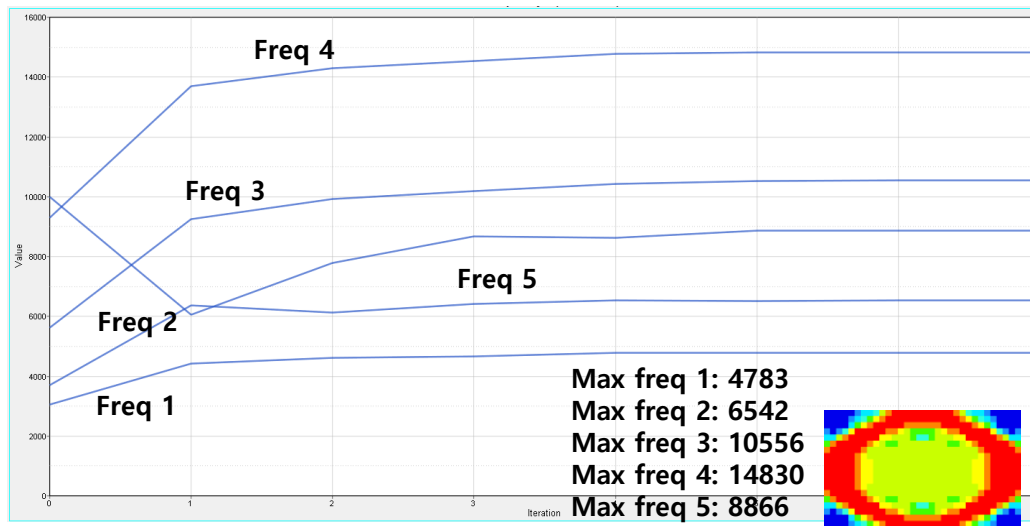
ADDITIONAL RESULTS

Maximum frequency: 1, 2



1,2차 고유주파수 최대화 결과

Maximum frequency: 1, 2, 3, 4, 5



1,2,3,4,5차 고유주파수 최대화 결과

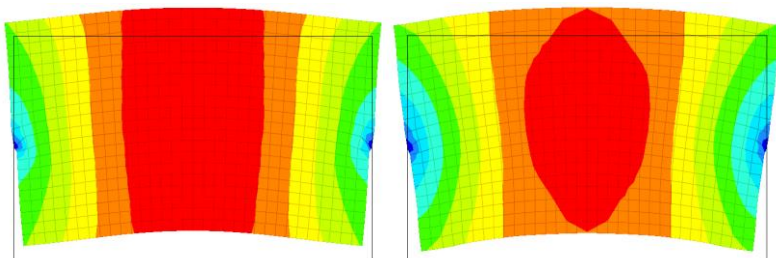
ADDITIONAL RESULTS

Mode shape 비교 (maximum frequency: 1, 2, 3, 4, 5)

1차 모드

Initial iteration

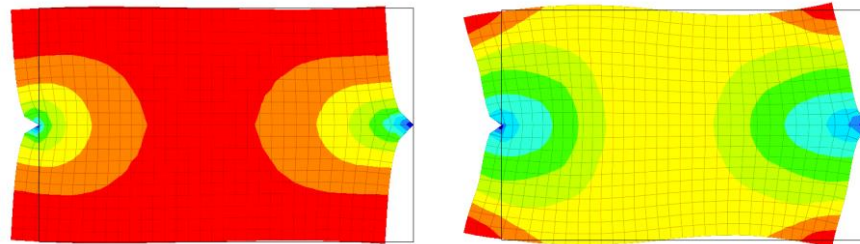
Final iteration



2차 모드

Initial iteration

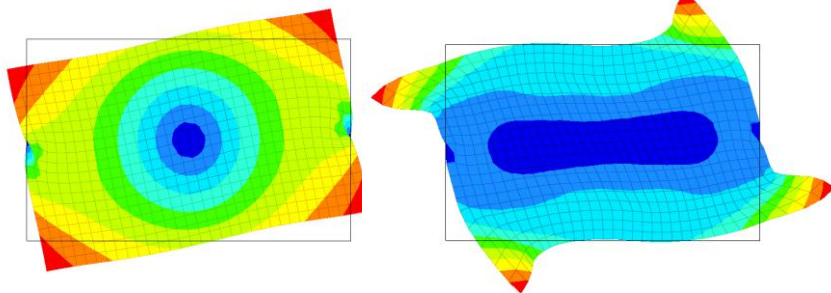
Final iteration



3차 모드

Initial iteration

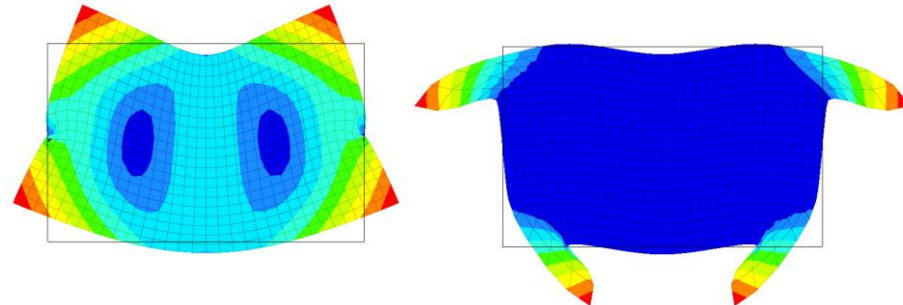
Final iteration



4차 모드

Initial iteration

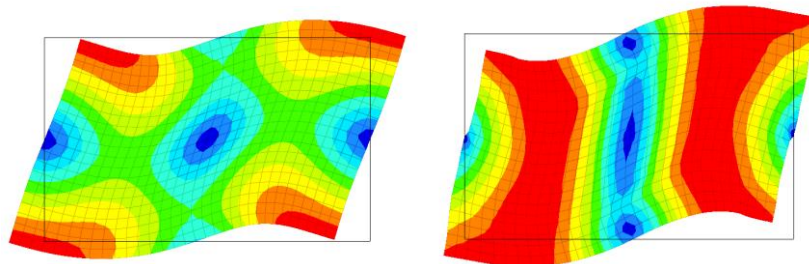
Final iteration



5차 모드

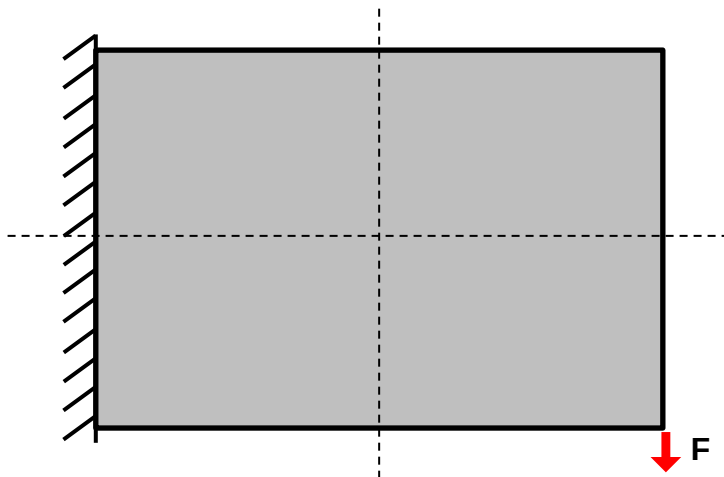
Initial iteration

Final iteration

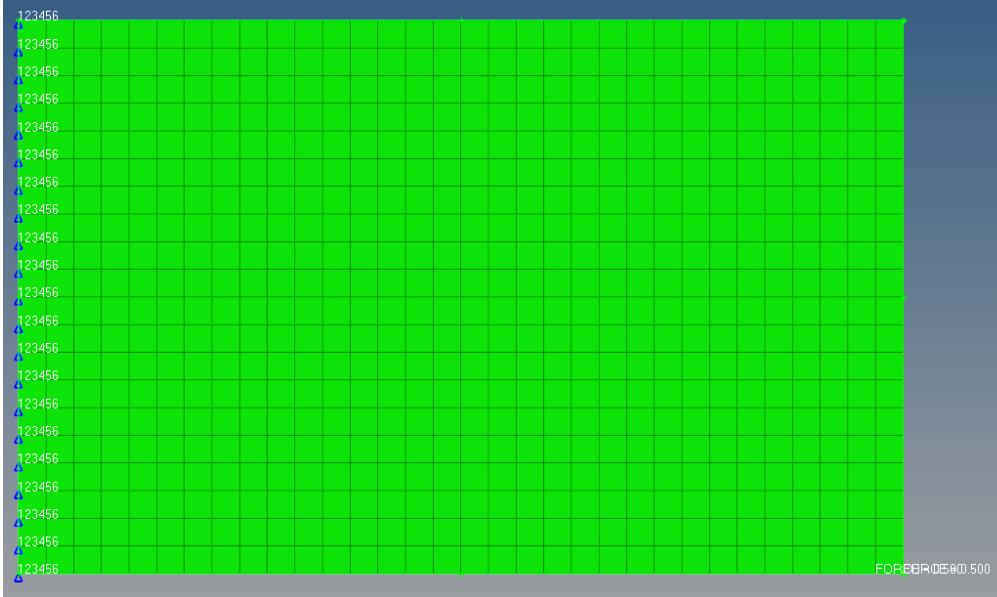


2D STRUCTURE

목적함수: 컴플라이언스 최소화
구속조건: 부피율 + 대칭조건



하중조건 변경



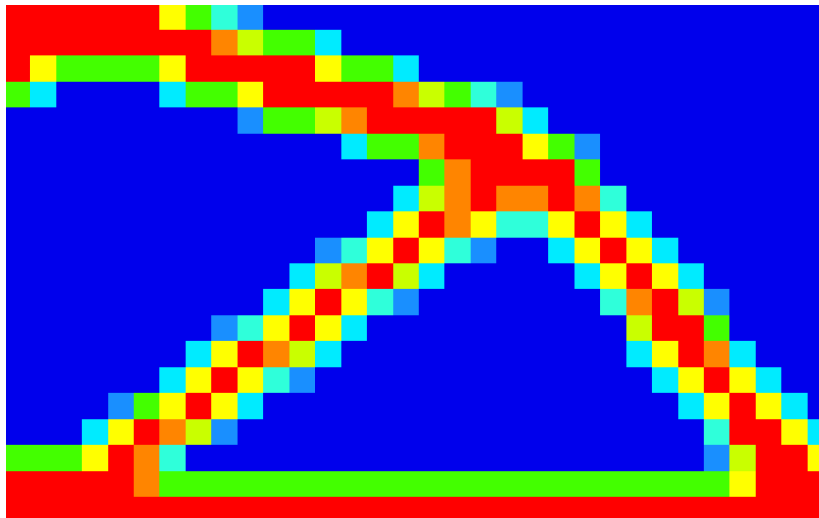
한쪽면 고정구속

하단 끝점 Y방향 집중하중
(-1/2 N) 부여

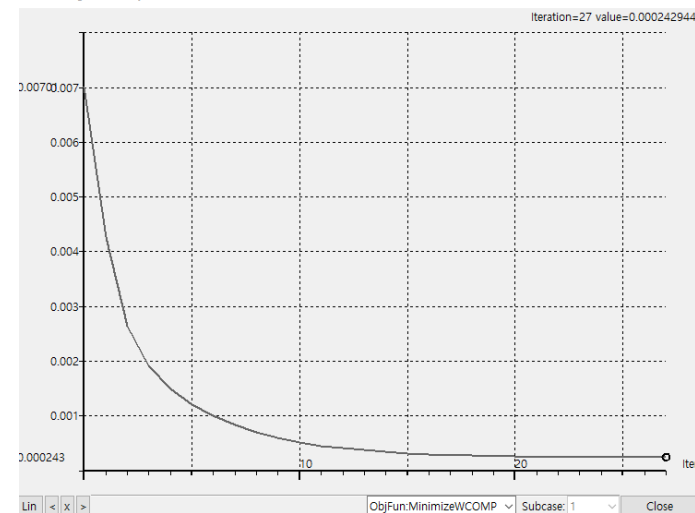


Minimize compliance
구속조건 : 부피율 $\leq 30\%$

최적설계 결과 확인

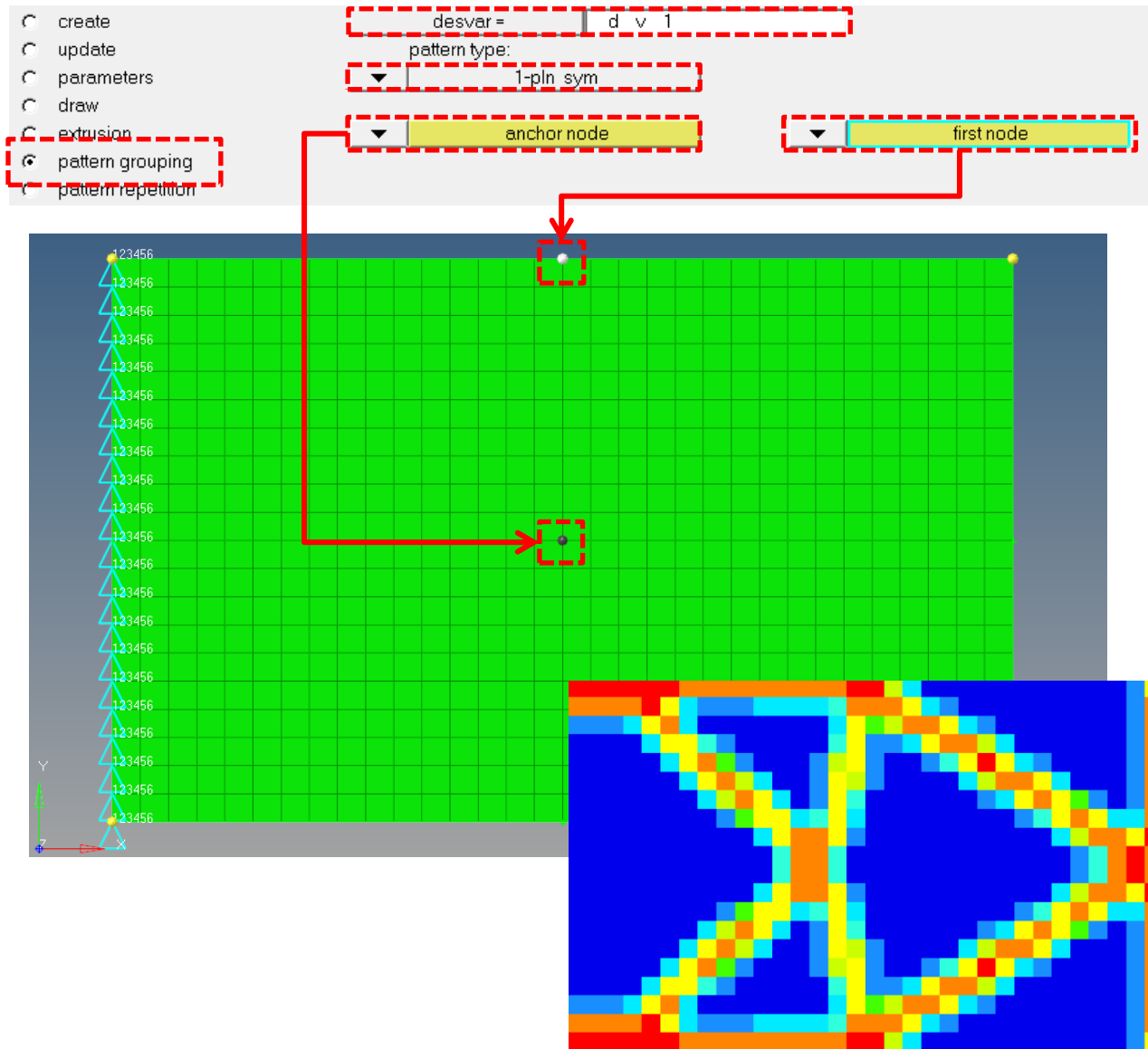


Convergence history for <week10_4_1.fem>



OBJ = $2.42e-4$

제조조건 입력

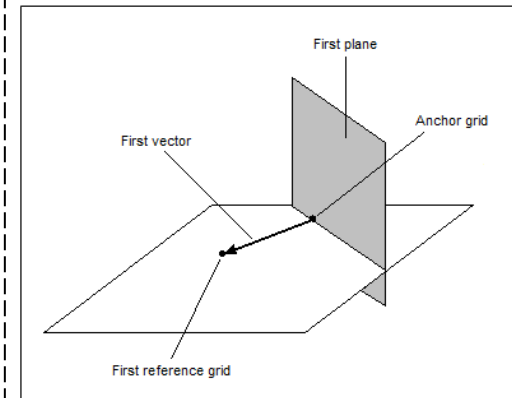


OBJ = $7.11e-4$

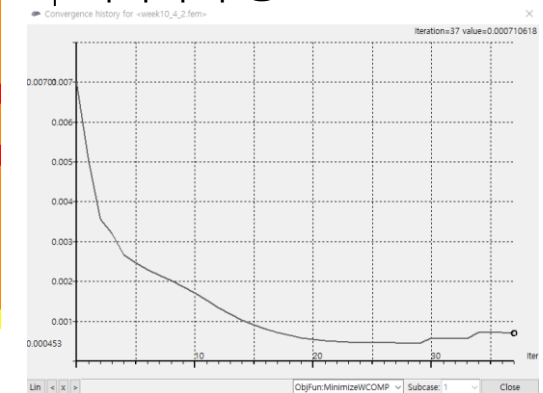
1 Analysis > optimization > topology > pattern grouping

Pattern type > 1-pin sym

대칭면 : XZ가 대칭면이 되도록 node 선택



최적화 수행



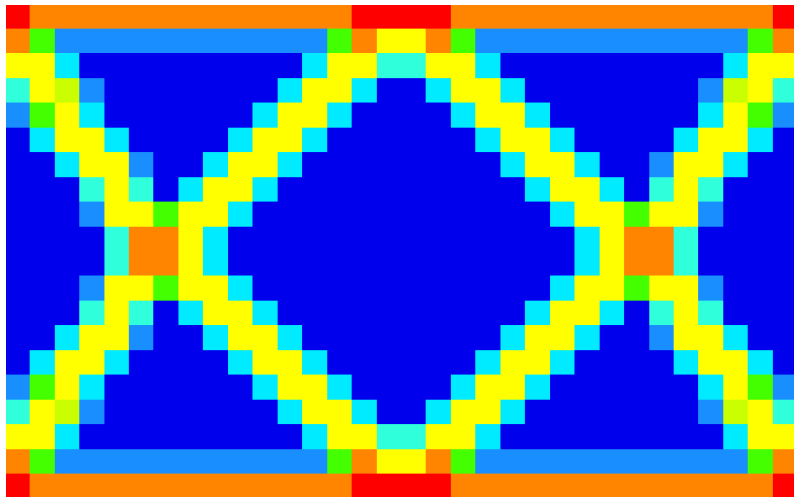
제조조건 입력

YZ 대칭



OBJ = 5.33e-4

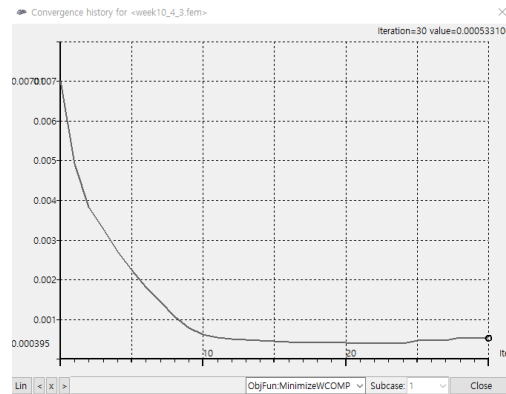
YZ+XZ 대칭



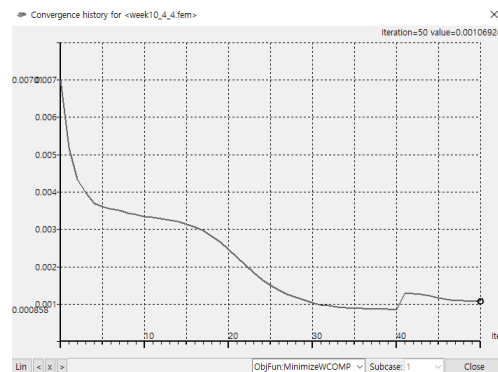
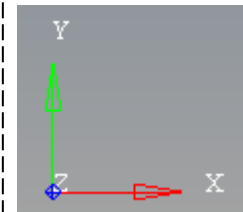
OBJ = 1.06e-3



YZ, YZ+ZX 대칭에 대해 수행



제조조건을 부여하는 경우
목적함수가 증가하는 것 확인
(대칭 없는 경우 2.42e-4)



3D STRUCTURE AUTOMOTIVE CONTROL ARM

목적함수: 부피 최소화
구속조건: 변위 + 제조
(금형 드로우 방향 고려)

서스펜션의 종류

Hotchkiss

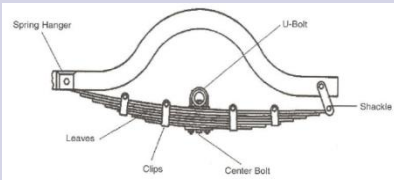
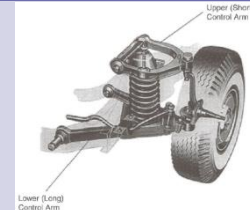
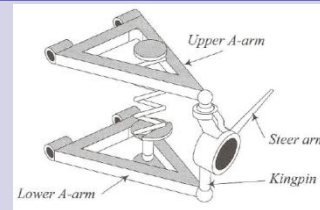


Figure 8.17. A multi-leaf spring. Adapted from TM 9-8000 (1985).



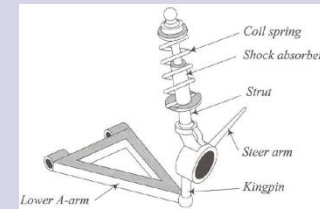
Double wishbone



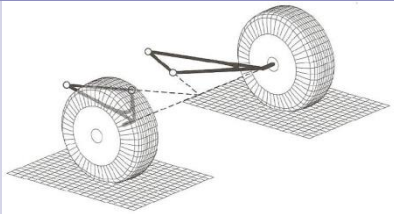
Trailing arm with twisted(torsion) beam



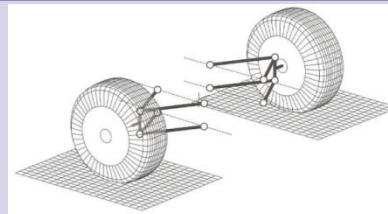
MacPherson



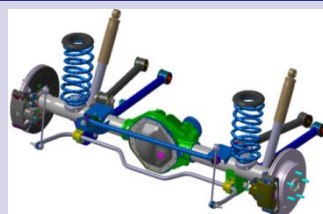
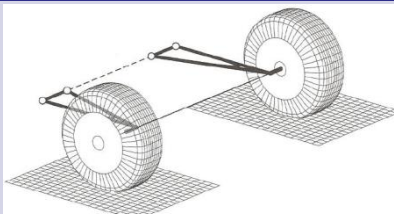
Semi-trailing arm



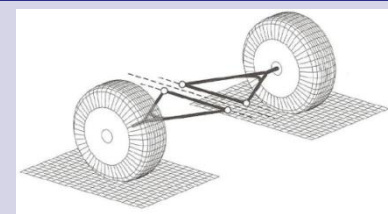
Multi-link



Trailing arm



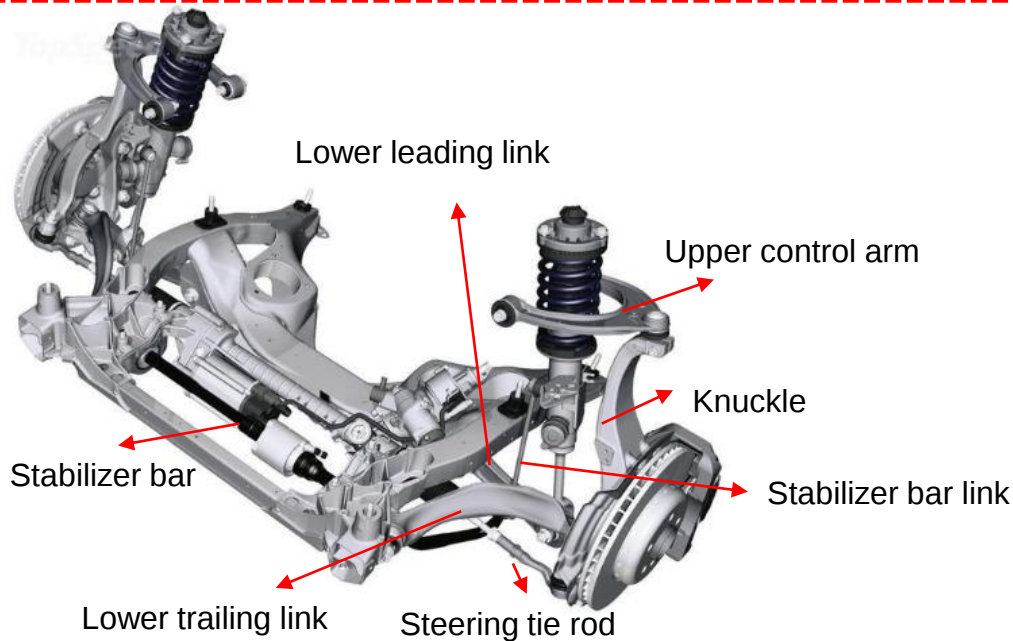
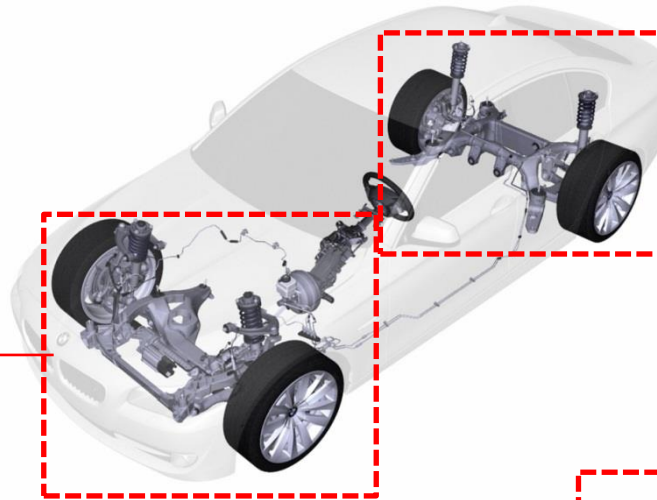
Swing(space) arm



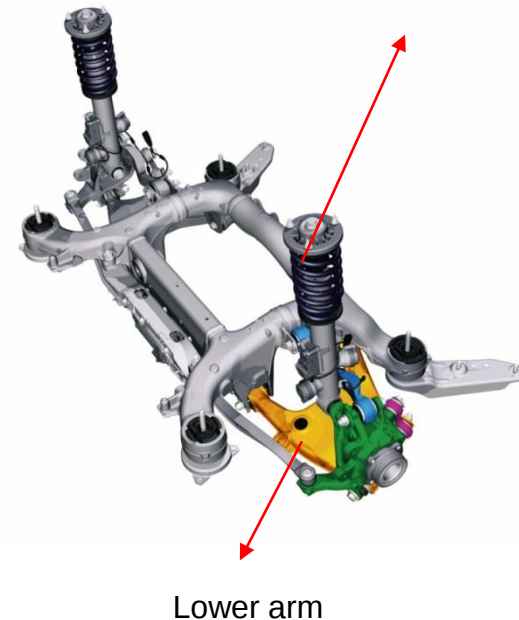
BMW NEW 5 SERIES

Front: Double wishbone type

Rear: Macpherson type



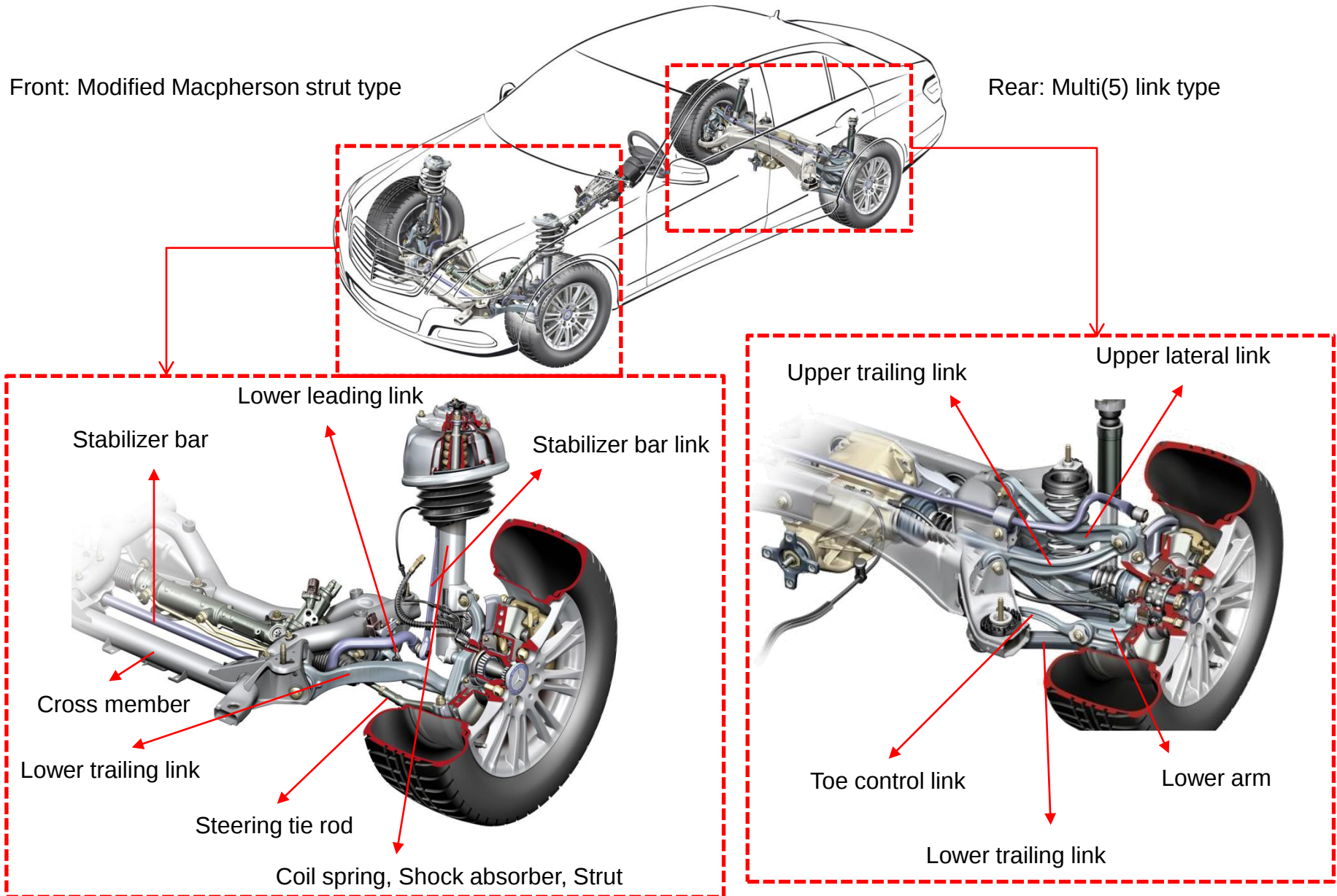
Coil spring, Shock absorber, Strut



BENZ E CLASS

Front: Modified Macpherson strut type

Rear: Multi(5) link type



예제: AUTOMOTIVE CONTROL ARM

기하 형상, 하중 및 경계조건

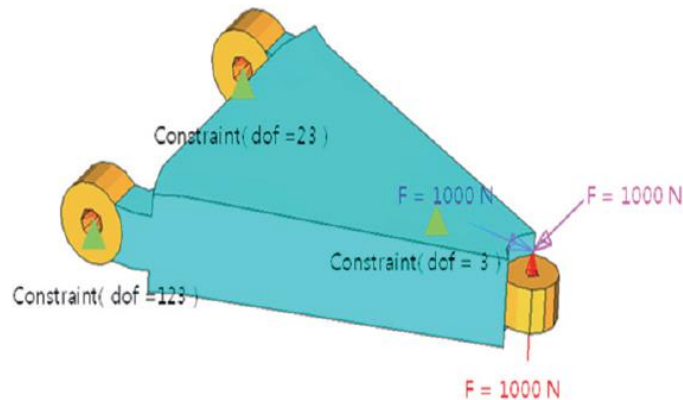
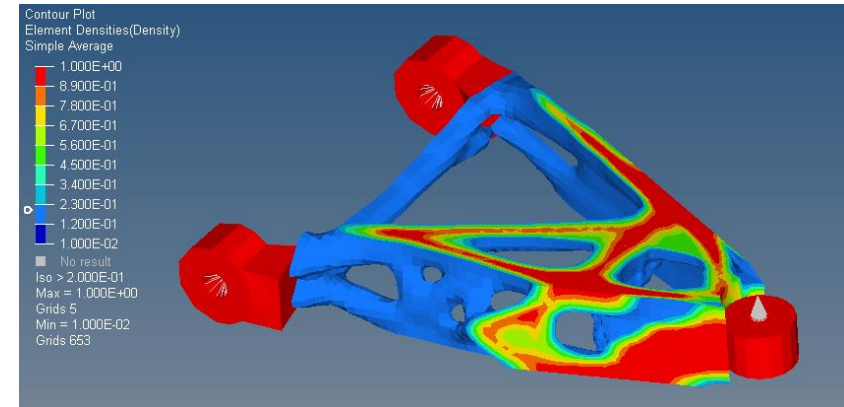


Fig 1 Finite element analysis

최적화 결과



최적설계 문제 정식화

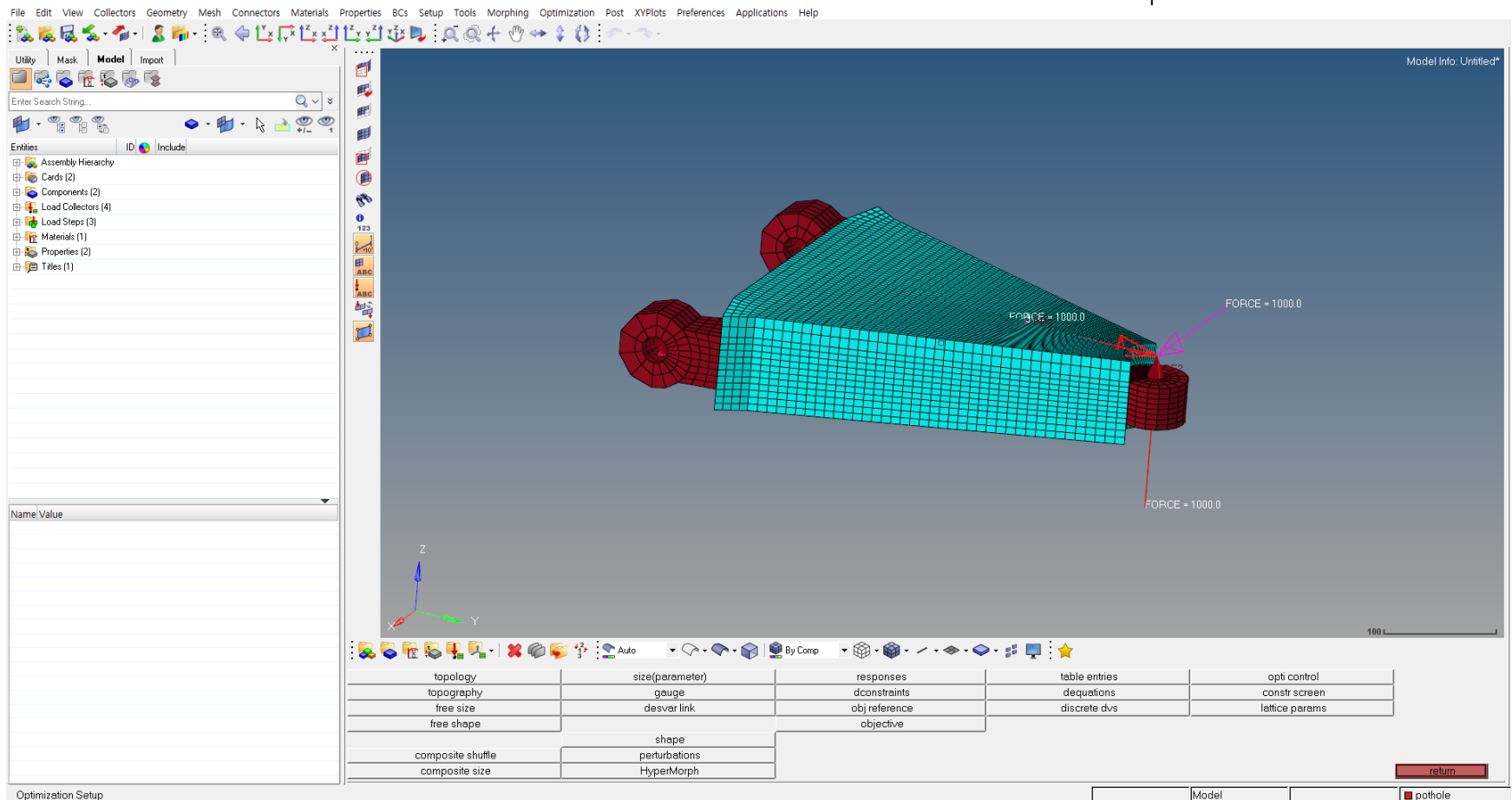
Objective:	Minimize volume.	
Constraints:	SUBCASE 1 -	The resultant displacement of the point where loading is applied must be less than 0.05mm.
	SUBCASE 2 -	The resultant displacement of the point where loading is applied must be less than 0.02mm.
	SUBCASE 3 -	The resultant displacement of the point where loading is applied must be less than 0.04mm.
Design variables:	Element density (and corresponding stiffness of the element) of each element in the design space.	

기하형상 불러오기

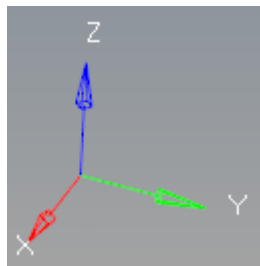
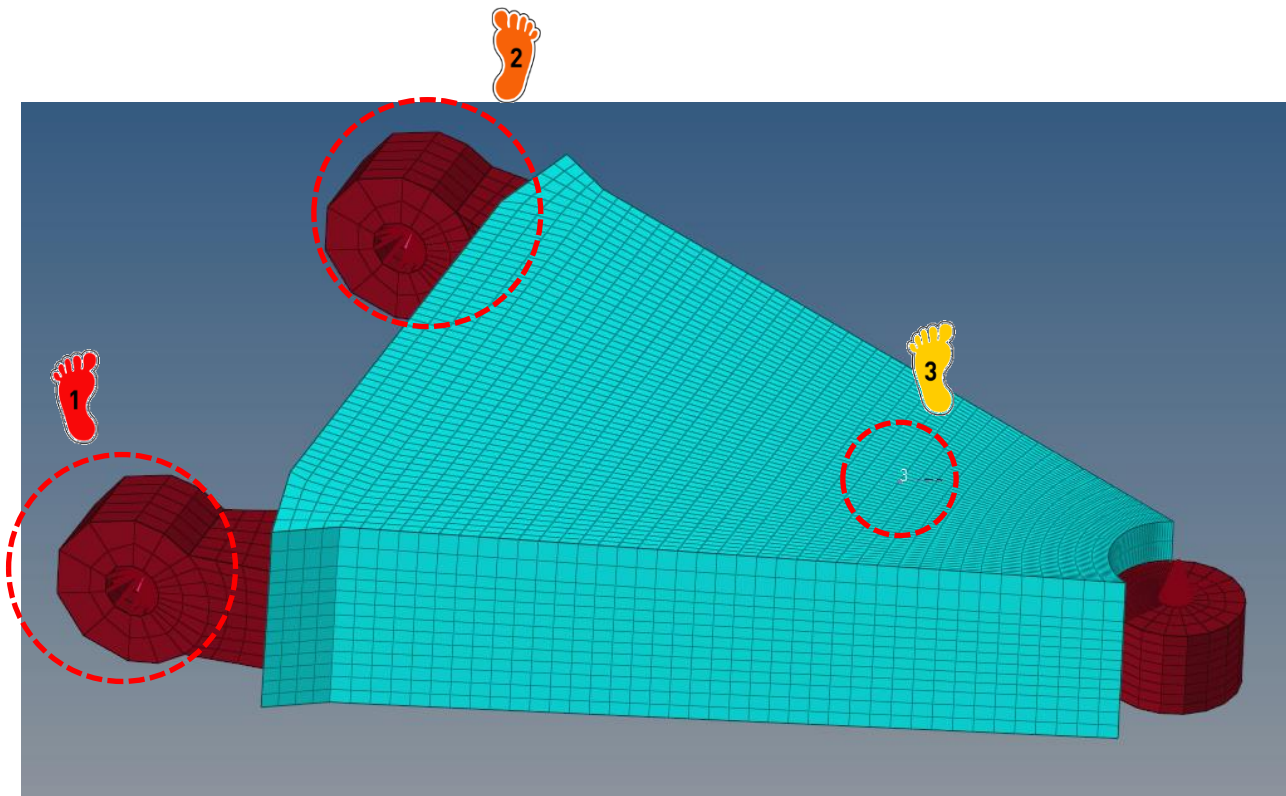


제공한 모델 파일을 열어서
기하형상 확인

메시, 재료 물성 및 특성이
입력되어있음



구속조건 및 하중조건 설정 [1]



1 T_x, T_y, T_z 구속

2 T_y, T_z 구속

3 T_z 구속

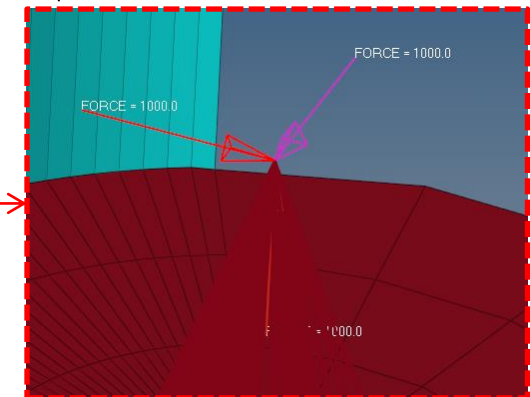
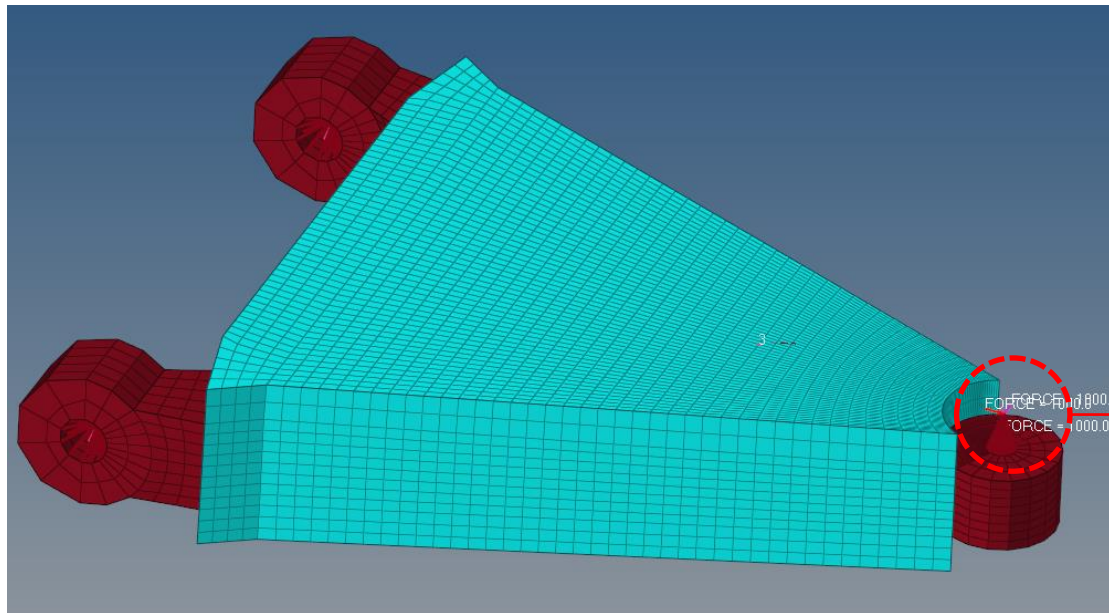
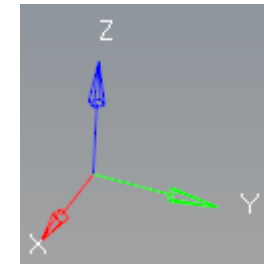
강체요소 가운데 절점을 구속조건으로 설정

구속조건 및 하중조건 설정 [2]

Load Collectors (4)			
	spc	1	0
	brake	2	0
	corner	3	0
	pothole	4	0
Load Steps (3)			
	brake	1	0
	corner	2	0
	pothole	3	0

1 하중조건을 설정할 때 하중세트
를 구별하여 총 3가지의 하
중을 생성

case1: x 방향 1000 N
case2: y 방향 1000 N
case3: z 방향 1000 N



DESIGN VARIABLE SETTING

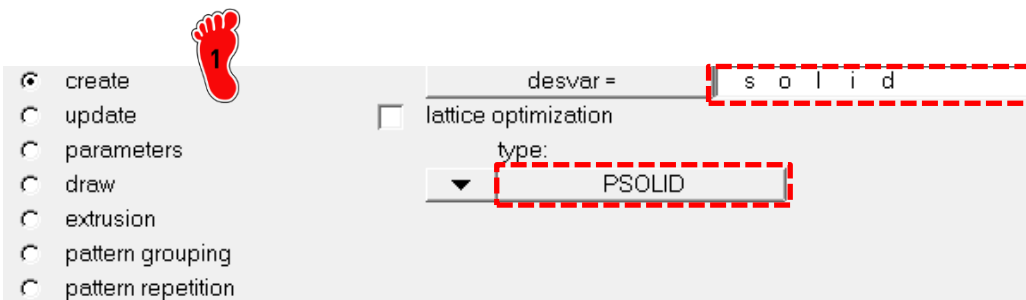
→ **Design variable**

→ **Responses**

→ **Objective**

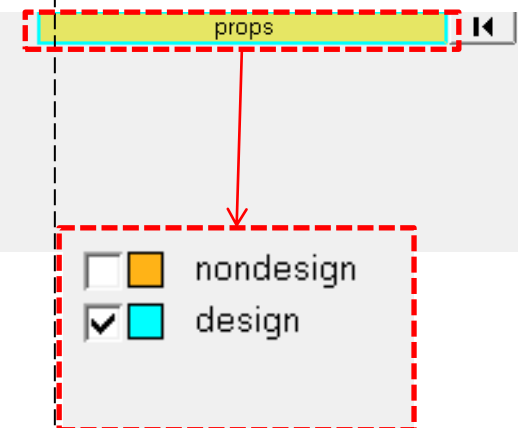
→ **Dconstraints**

→ **Opti control**



Analysis > optimization > topology

create



RESPONSE SETTING (1)

→ Design variable

→ Responses

→ Objective

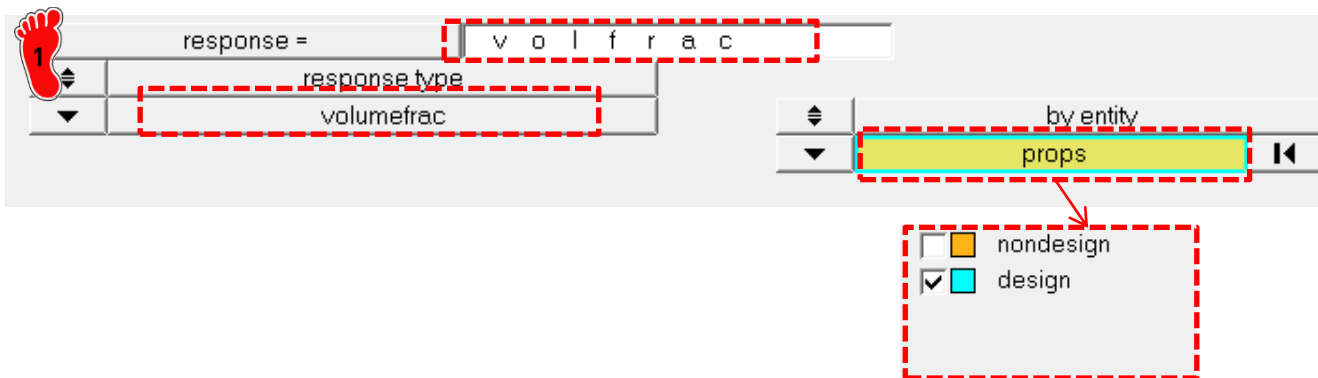
→ Dconstraints

→ Opti control



Analysis > optimization > responses

volumefrac > create



RESPONSE SETTING (2)

→ Design variable

→ **Responses**

→ Objective

→ Dconstraints

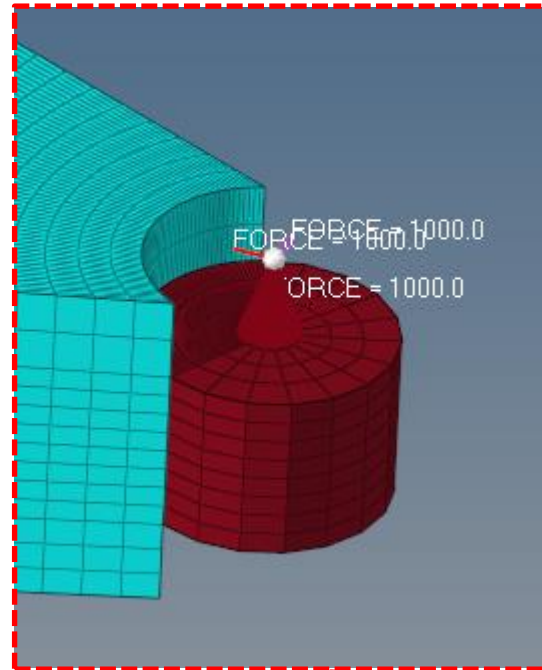
→ Opti control



Analysis > optimization > responses

total disp

create



response =

d i s p

response type

static displacement

nodes

☐ numbers

no regionid

☐ dof1

☐ dof2

☐ dof3

☒ total disp

☐ dof4

☐ dof5

☐ dof6

☐ total rotation

OBJECTIVE SETTING

→ Design variable

→ Responses

→ **Objective**

→ Dconstraints

→ Opti control



Analysis > optimization >
objective

create



min

response =

v o l f r a c

CONSTRAINTS SETTING

→ Design variable

→ Responses

→ Objective

→ **Dconstraints**

→ Opti control



Analysis > optimization > dconstraints

3개의 constraints

Brake ≤ 0.05

Corner ≤ 0.02

Pothole ≤ 0.04

각각 생성

Optimization Constraints (3)			
	constr1	1	0
	constr2	2	0
	constr3	3	0

constraint =

lower bound =

upper bound =

response =

☒ brake

☐ corner

☐ pothole

CONTROL SETTING



Analysis > optimization >
opti control

→ Design variable

→ Responses

→ Objective

→ Dconstraints

→ Opti control

DESMAX: Maximum number of design iterations

OBJTOL: 0.5% change in the objective function

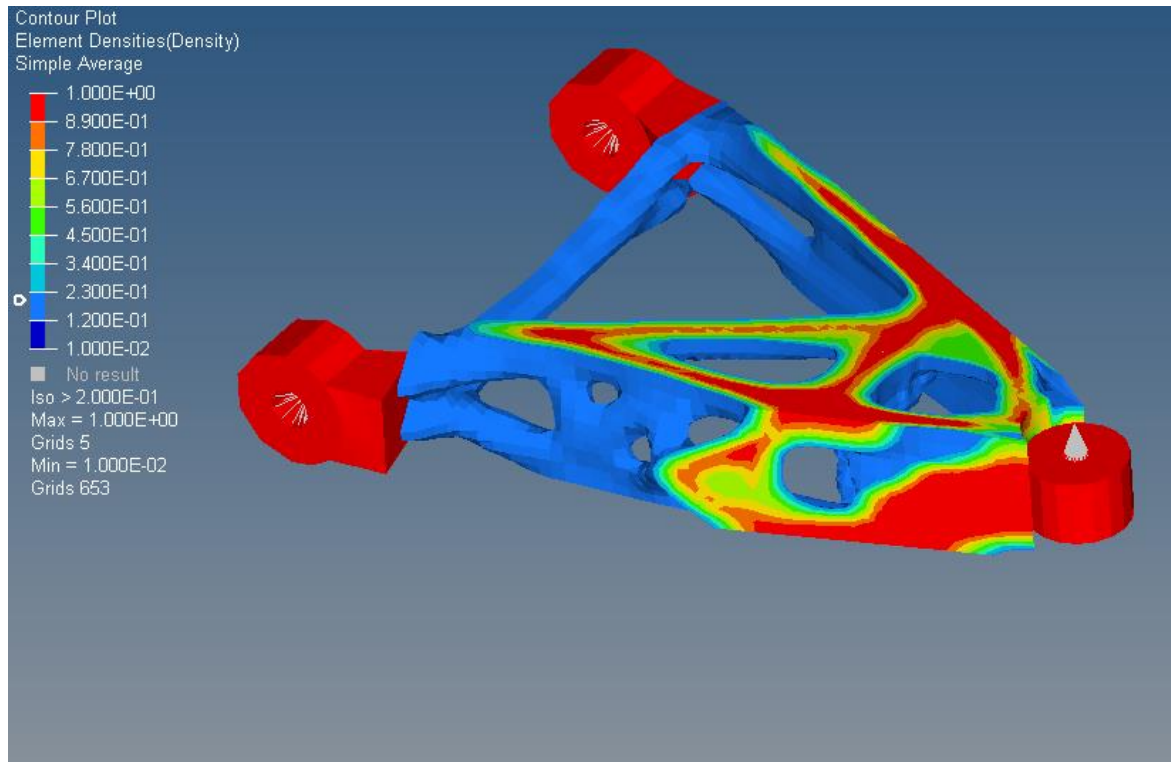


☒	DESMAX=	50	☒	OBJTOL=	0.005
☐	MINDIM=	0.000	☐	DELSIZ=	0.500
☐	MATINIT=	0.600	☐	DELSHP=	0.200
☐	MINDENS=	0.010	☐	DELTOP=	0.500
☒	DISCRETE=	3.000	☐	GBUCK=	0
☒	CHECKER=	1	☐	MAXBUCK=	10
☐	MMCHECK=	0	☐	DISCRT1D=	1.000

DISCRETE: Higher values decrease the number of elements that remain between 0 and 1.

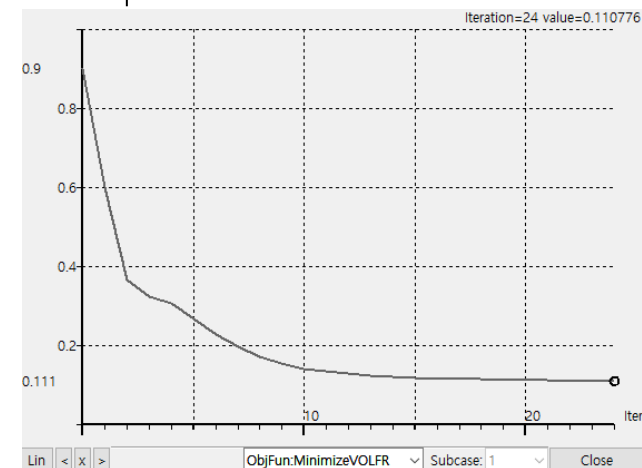
CHECKER: Checkerboard control option. (0 = no checkerboard control)

최적화 결과



1 결과 형상 확인

2 Iso > apply



By Comp

Result type: Element Densities (s)
Density

Selection: Components

Resolved in: System

Averaging method: Simple

Variation < 30 (%)

Averaging Options...

Use Contour Settings

Apply

Current value: 0.2

0.00999999885 1

Increment by: 1

Show values: Above

Color

Use corner data

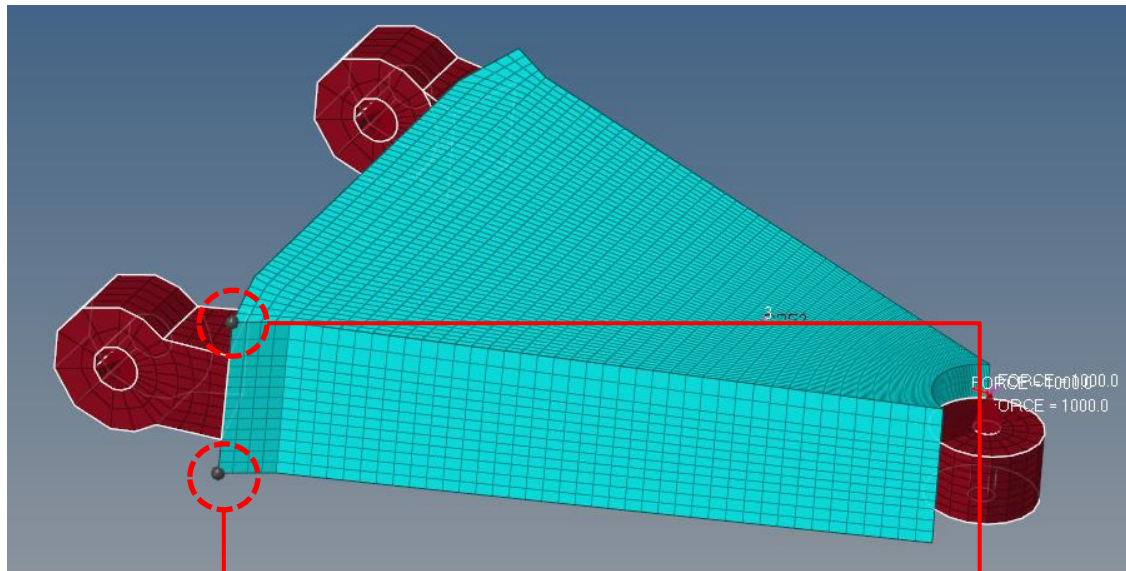
Use tracking system

Show midside node results

제조 조건 추가

- Topology Optimization Manufacturability
 - Member Size Control
 - Draw Direction Constraints
 - Extrusion Constraints
 - Pattern Repetition
 - Pattern Grouping
 - Combine Pattern Repetition and Grouping

제조조건 입력



- ☐ create
- ☐ update
- ☐ parameters
- ☒ draw
- ☐ extrusion
- ☐ pattern grouping
- ☐ pattern repetition

desvar = solid

draw type: single

anchor node

first node

no hole

stamp

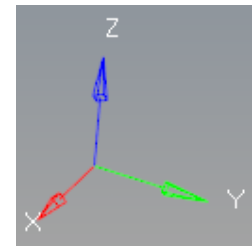
obstacle: props

- ☒ nondesign
- ☐ design

1 Analysis > optimization > topology > draw

Draw direction
: First node > Anchor node

Z방향

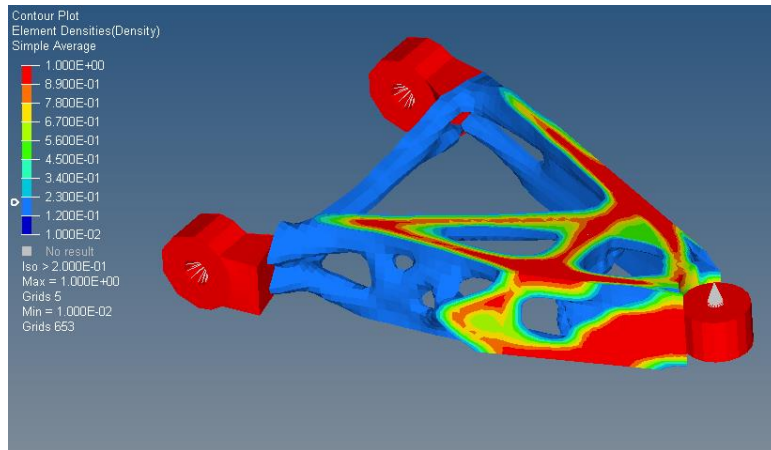


Single draw direction

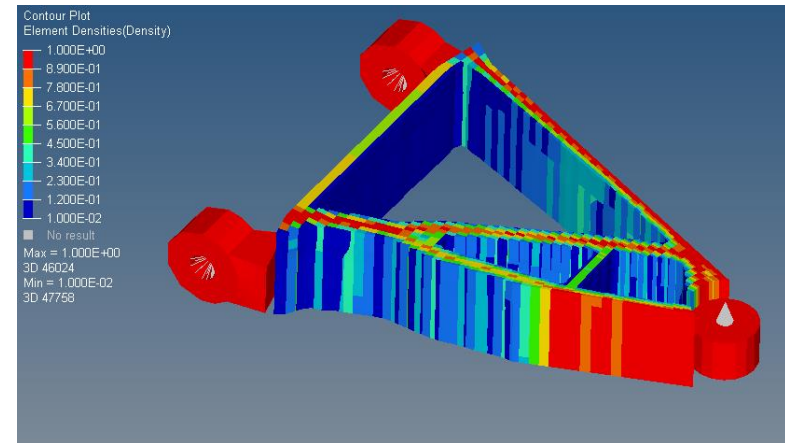


Dual draw direction

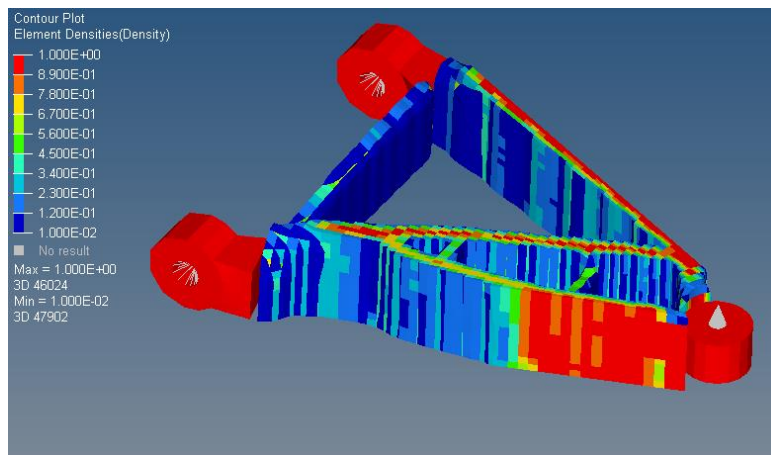
최적화 결과 비교



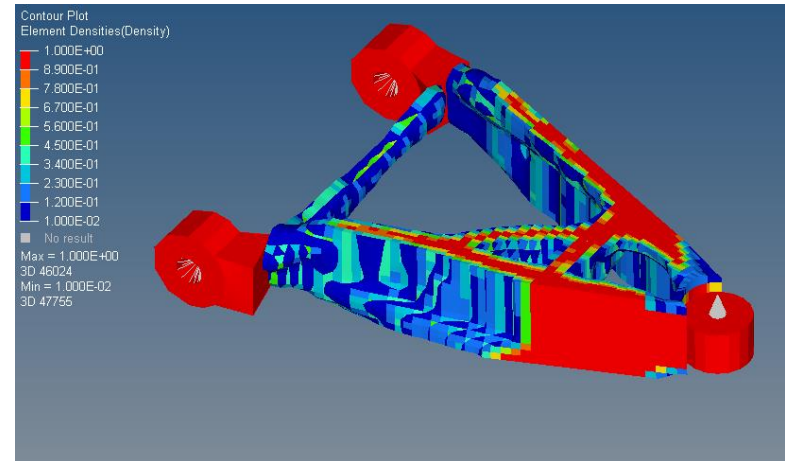
제조조건 없음(69쪽)
Obj = 0.1107



Extrusion(z), no twist
Obj = 0.1913



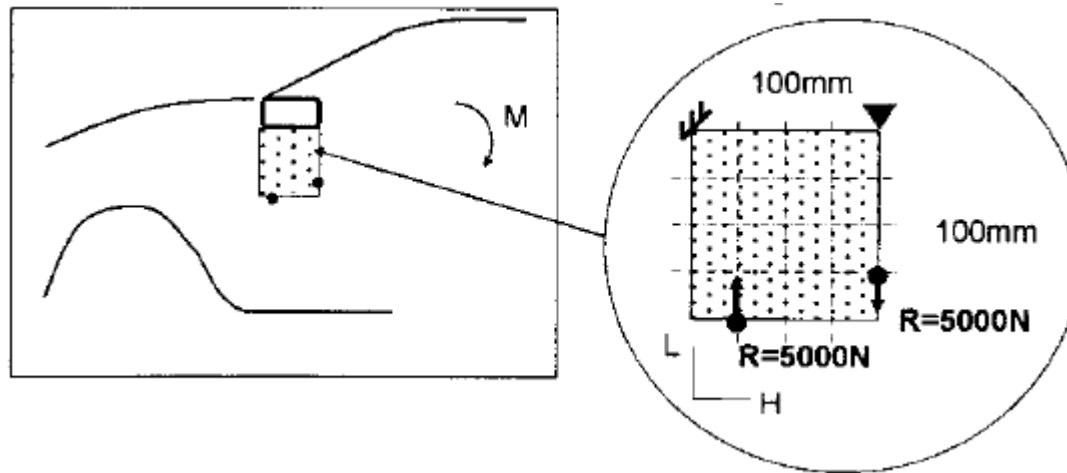
Draw single(z)
Obj = 0.1836



Draw split(z)
Obj = 0.1400

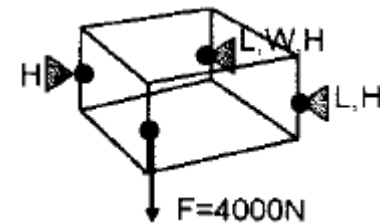
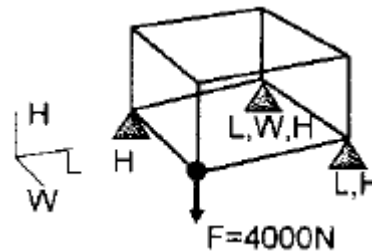
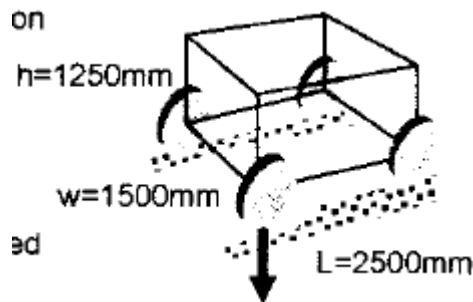
숙제: 2D 문제

- The steering column bracket holds the steering column at two points (the solid black circle above). When the maximum moment is applied to the steering column, the bracket must react loads at the attachment R as shown.
- Determine the optimal shape of the steel bracket to maximize the stiffness under loads R. The bracket is flat ($w=0$) and at most 100mm x 100mm



숙제: 3D 문제

- The van shown is supported on three wheels with the fourth wheel unsupported. This condition applies a force downward at the left front suspension ($F=4000\text{N}$). We wish to maximize the stiffness under this load condition for a fixed volume of structural material. The structure is made of a set of interconnected steel beams which are enclosed by the area shown.
- Determine the optimal shape for the four conditions shown below.



Suspension attachment: (1) at corners (2) mid-way up edge

