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# Análise de Estruturas Navais em Materiais Compostos pelo Método de Elementos Finitos

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*Jorge Nasseh*

# **Incertezas**

So what do we do? Anything. Something.  
So long as we just don't sit there.  
If we screw it up, start over. Try something else.  
If we wait until we've satisfied all the uncertainties, it  
may be too late.

Steve Jobs

# Incertezas

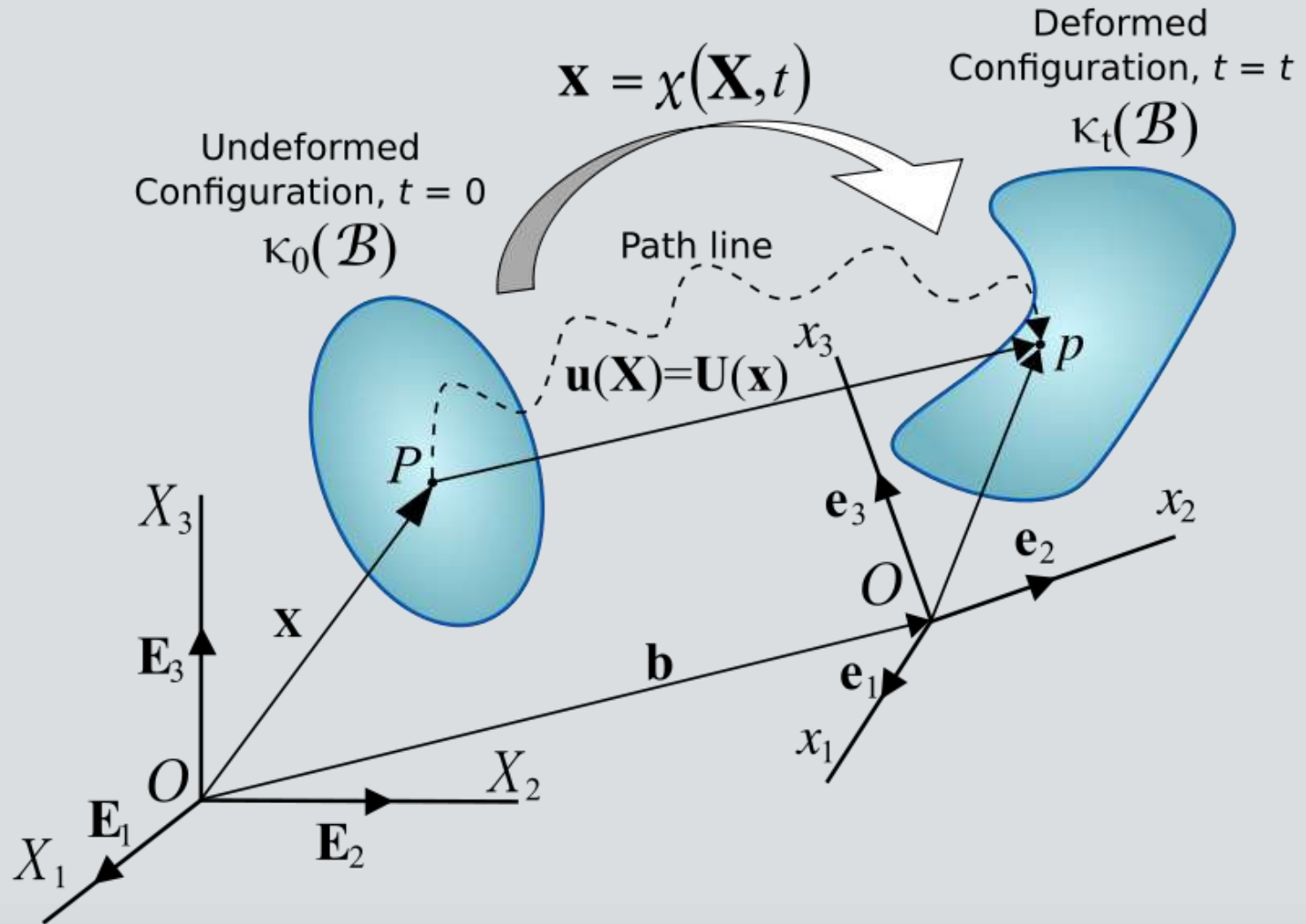
Eu nunca aprecio os fatos concretos deste mundo. Eles são quase sempre clichês, cópias de cópias. Eu prefiro perplexidade, dúvida e incerteza, não apenas porque fornece um modelo mais real deste mundo, mas porque essa é a maneira que nós, seres humanos, realmente somos.

José Saramago

# **Incertezas**

L'incertitude n'est pas une condition agréable, mais la certitude est absurde

Voltaire





# **Princípios da Análise Estrutural**

- ▶ Equações de Equilíbrio
- ▶ Leis Constituintes dos Materiais
- ▶ Condições de Contorno

# **Problema Estrutural**

- ▶ Solução Empírica
- ▶ Solução Analítica



“Hipótese refere-se a uma idéia inteligente ou a uma abordagem matemática conveniente que simplifique um problema complicado”

Sócrates

# Solução Analítica

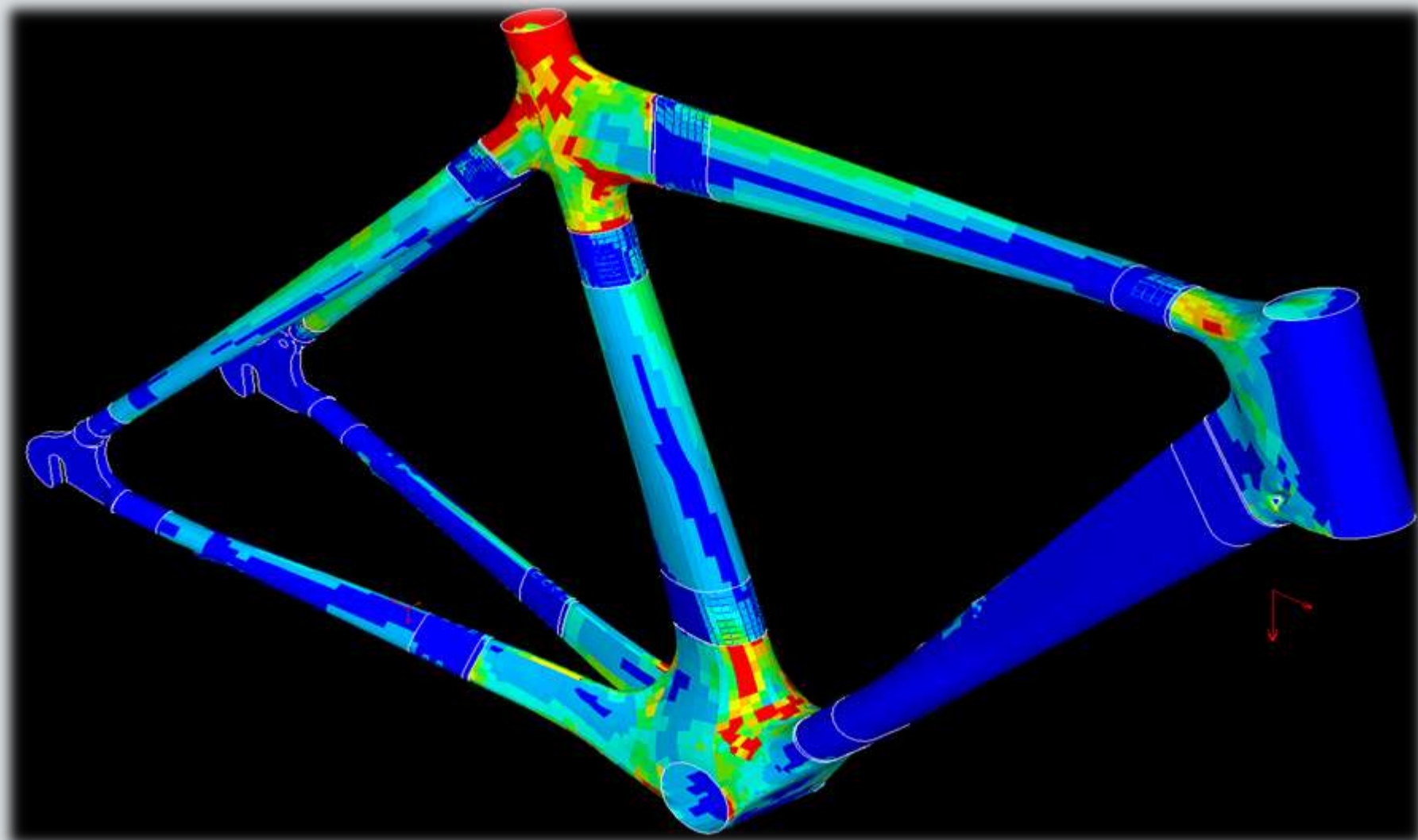
- ▶ Como Simplificar o Problema?
- ▶ Como Determinar as Equações de Equilíbrio?
- ▶ Como Determinar as Condições de Contorno?
- ▶ Como Determinar as Propriedades dos Materiais?
- ▶ Quais os Experimentos que podemos usar para justificar nossas hipóteses?
- ▶ Quantas vezes devemos interagir o Modelo Matemático?
- ▶ Quais os erros que podemos admitir?
- ▶ Quanto tempo posso dispor para conseguir uma solução?
- ▶ Qual o custo desta solução?

# Princípios da Análise Estrutural

- ▶ Os princípios básicos da análise estrutural e o método dos elementos finitos são simples de se entender mas as soluções dos problemas não são necessariamente fáceis e envolvem vários conceitos matemáticos.
  - ▶ Matemática
  - ▶ Álgebra Linear
  - ▶ Cálculo Diferencial

# Equações de Equilíbrio

$$\int_{S_u} \mathbf{u}^T \delta \mathbf{T} dS + \int_V \mathbf{u}^T \delta \mathbf{f} dV = \int_V \boldsymbol{\epsilon}^T \delta \boldsymbol{\sigma} dV$$





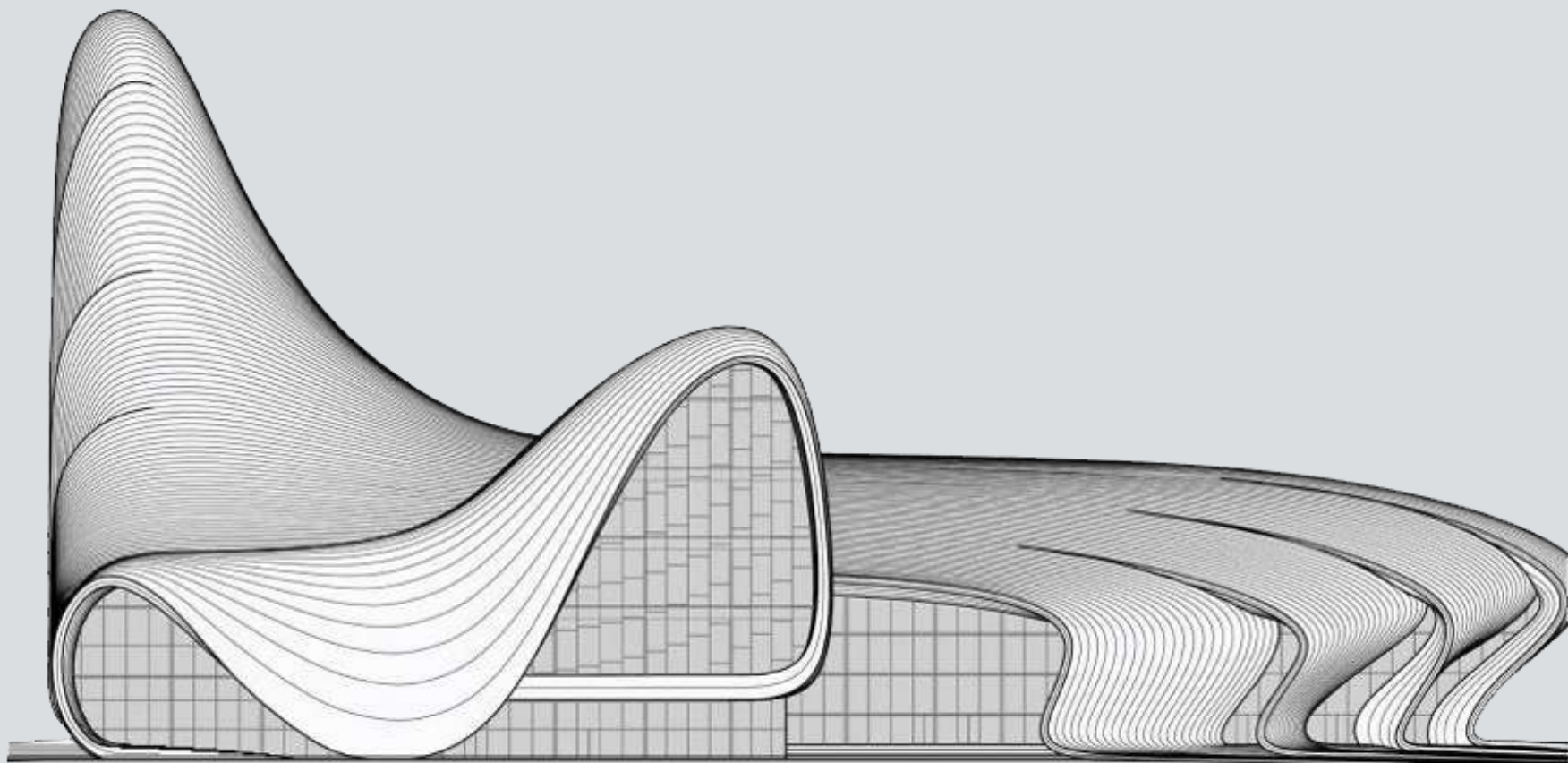


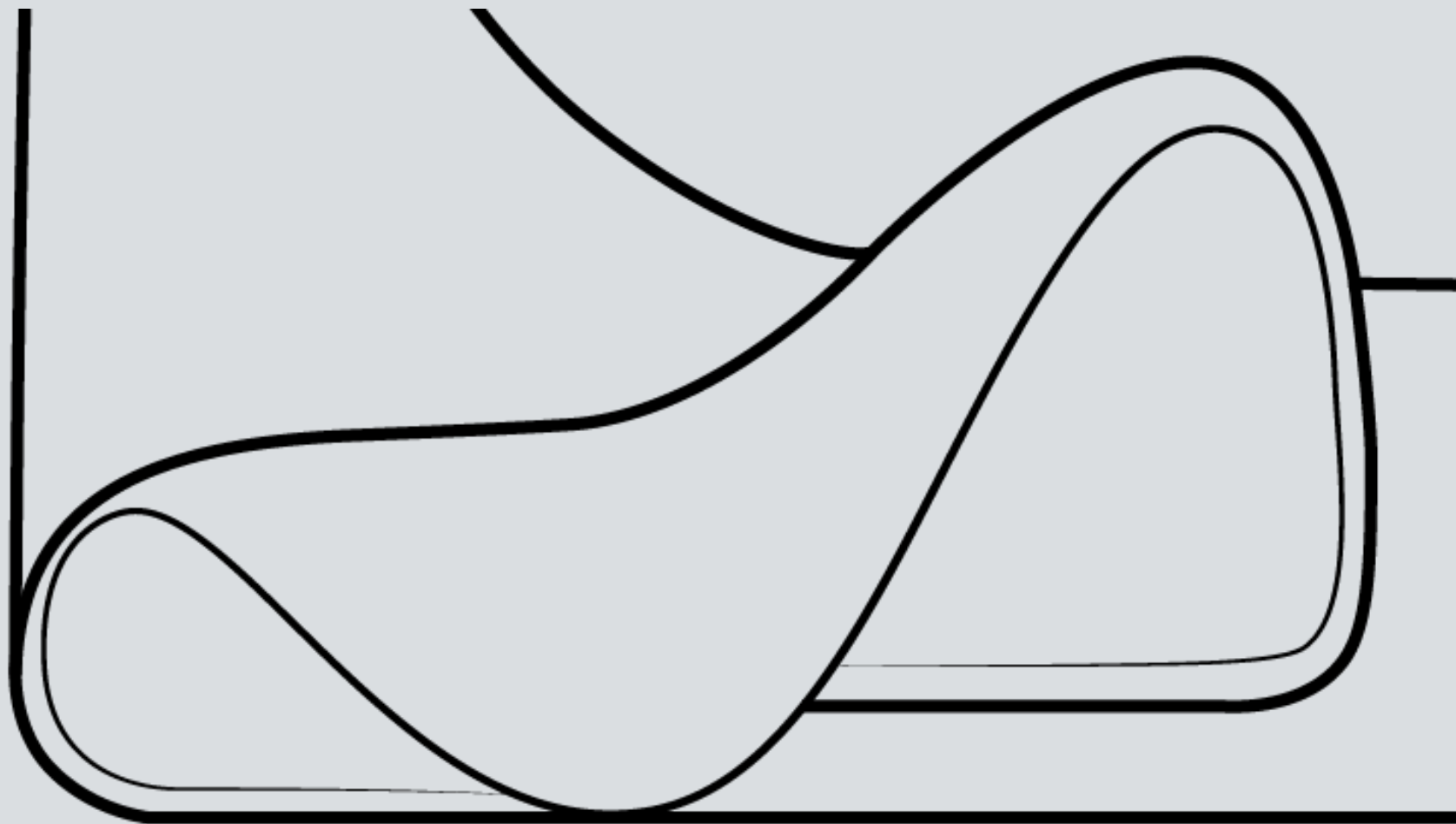


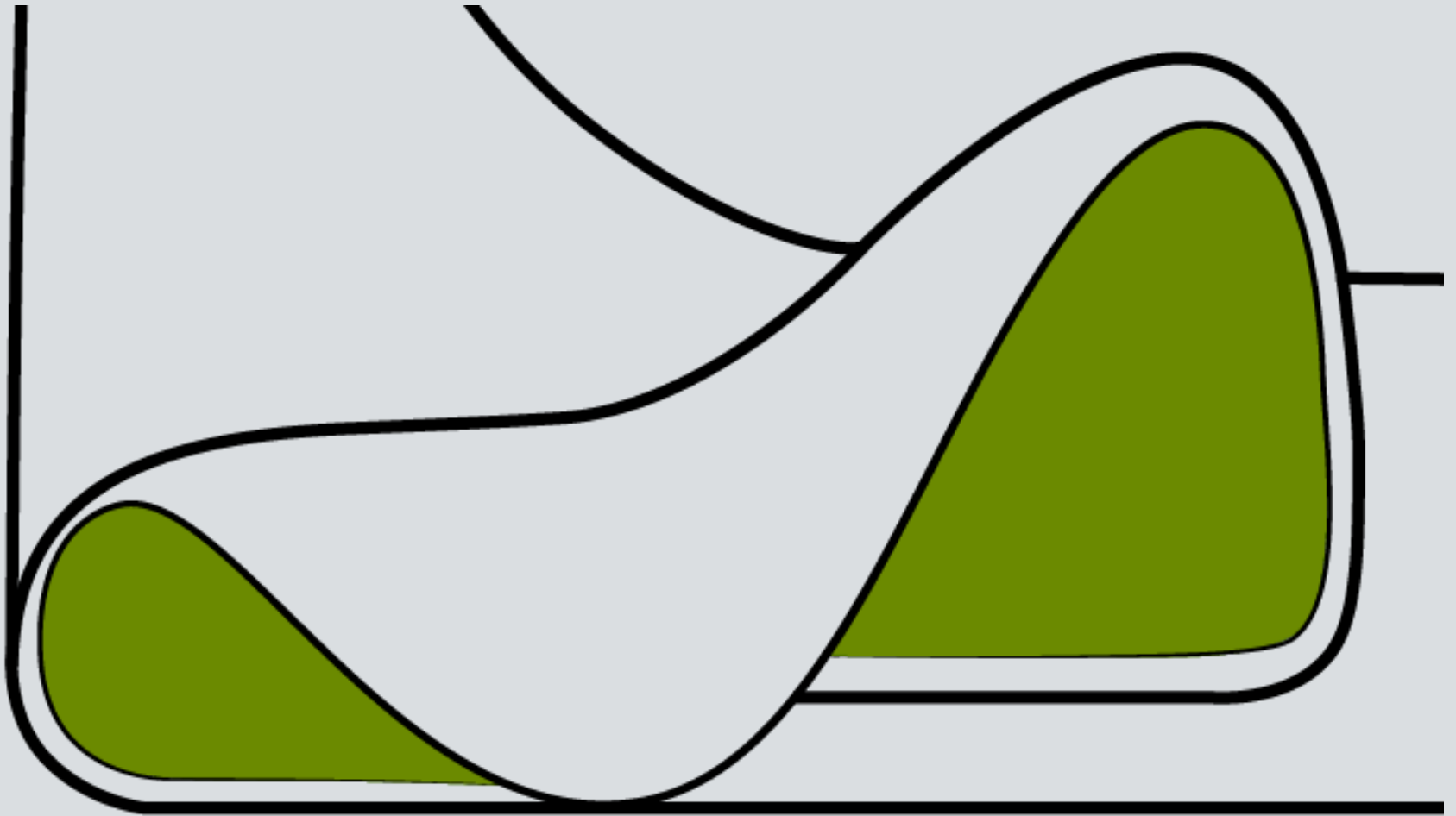


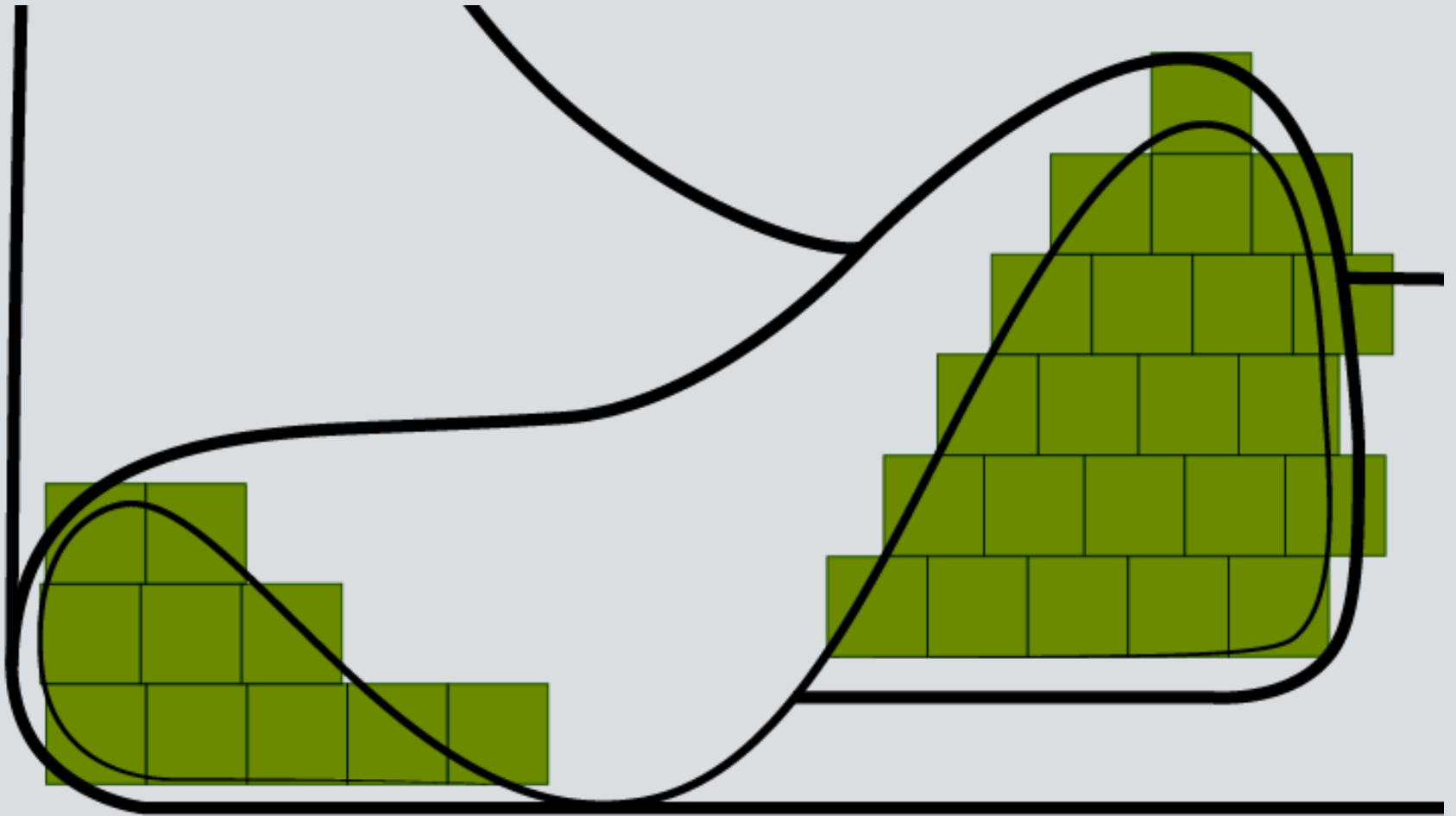




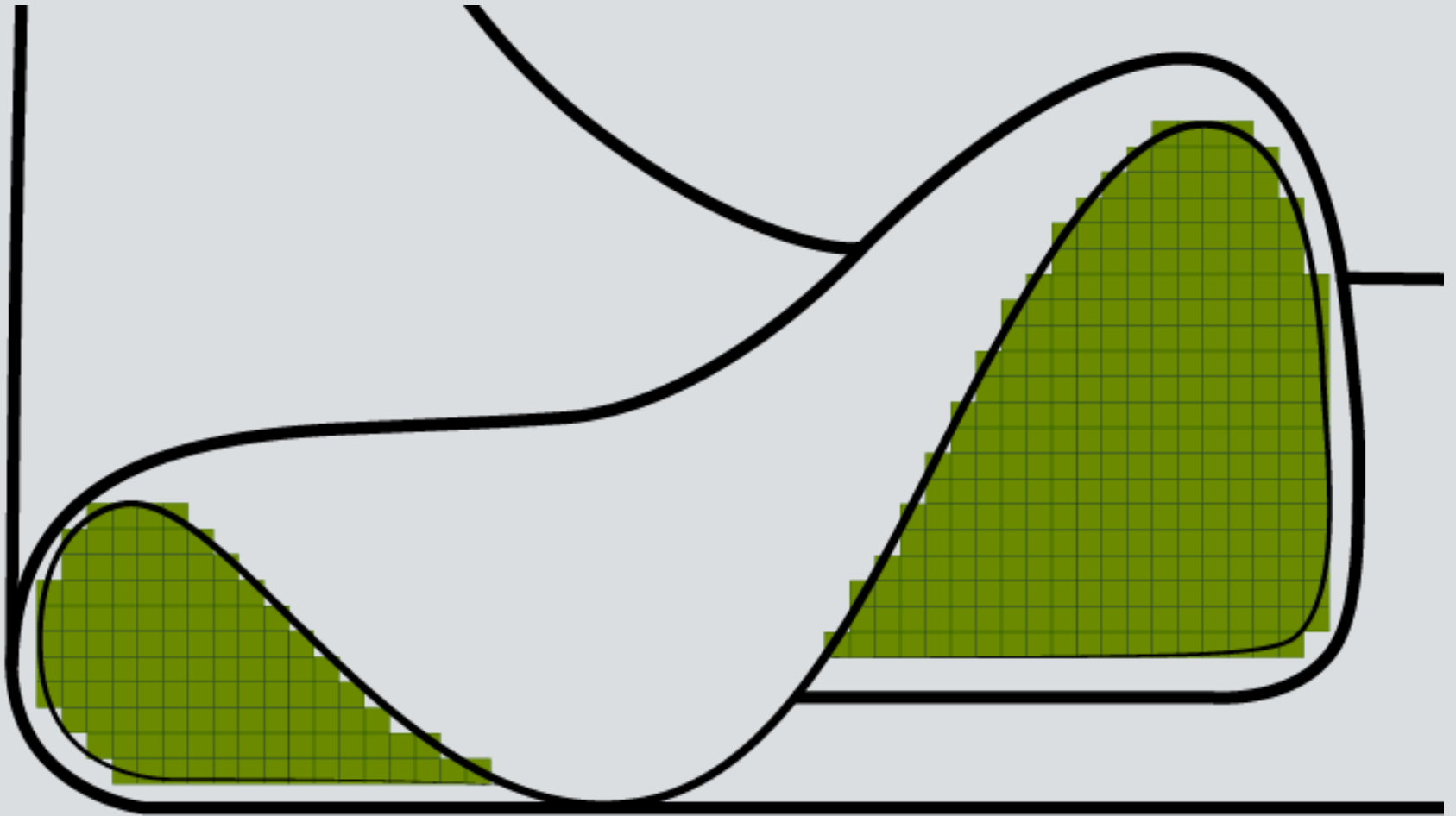




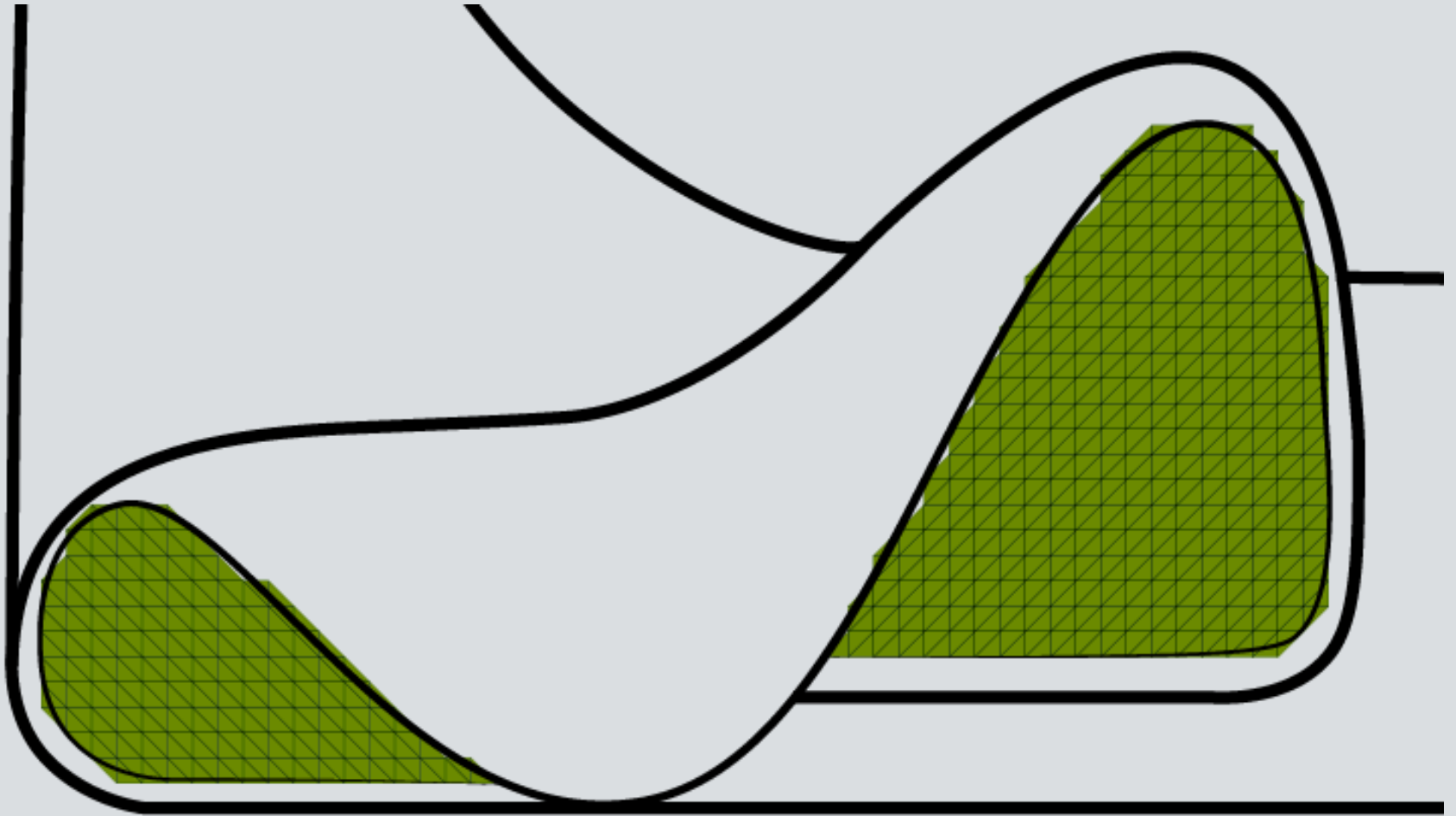


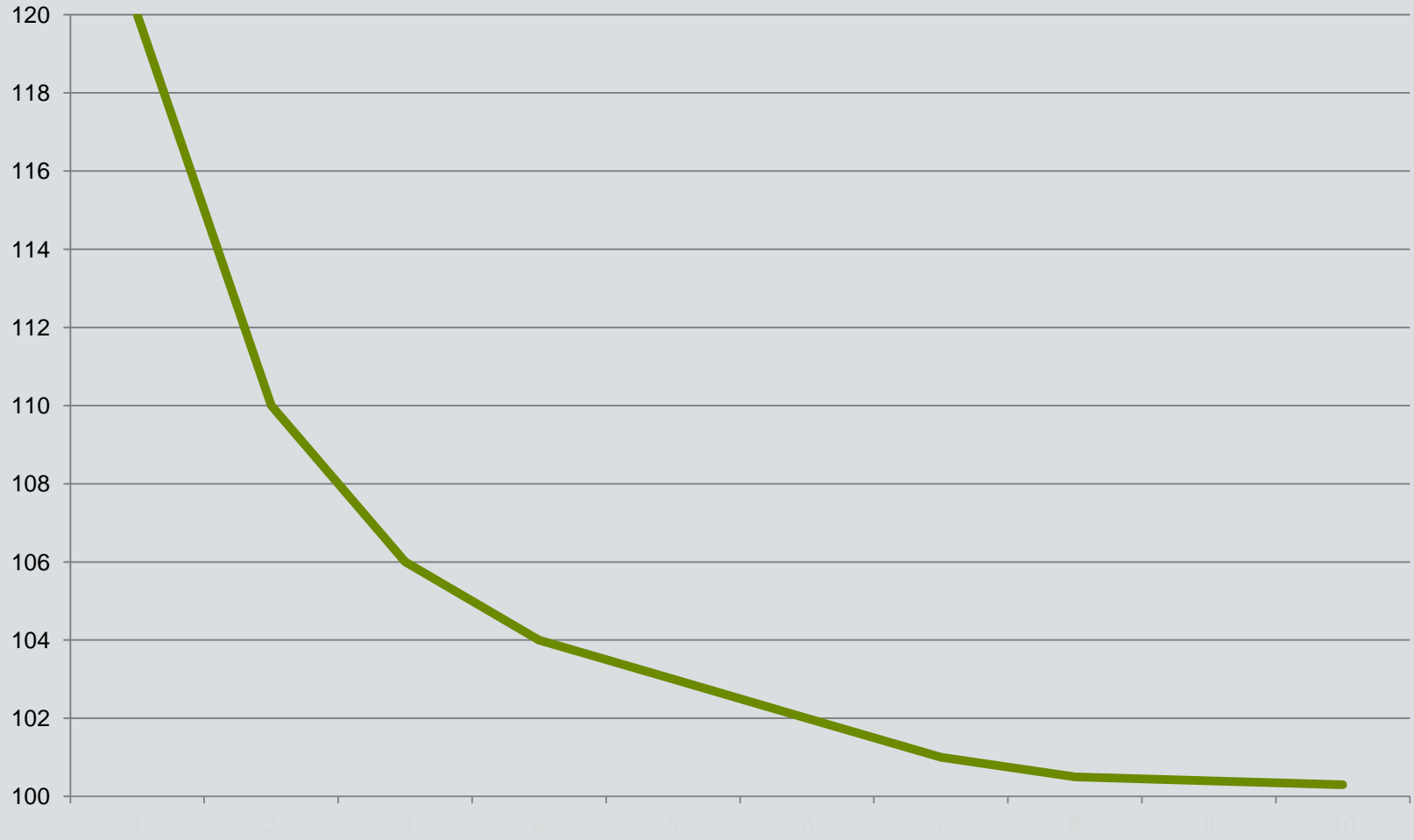






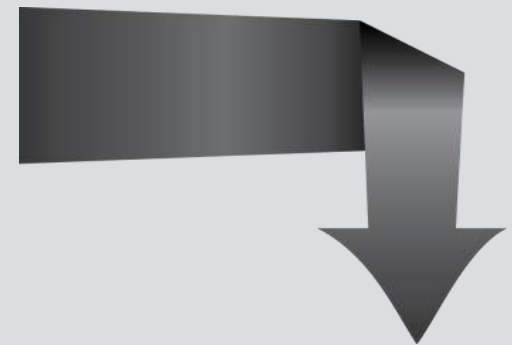






# Análise Estrutural

- ▶ Efeito das Cargas sobre a Estrutura e seus Membros
- ▶ Modelo Matemático para Cálculo de:
  - ▶ Deformações
  - ▶ Forças Internas
  - ▶ Tensões
  - ▶ Reações nos Apoios
  - ▶ Acelerações
  - ▶ Estabilidade Estrutural
  - ▶ Fatores de Segurança ...

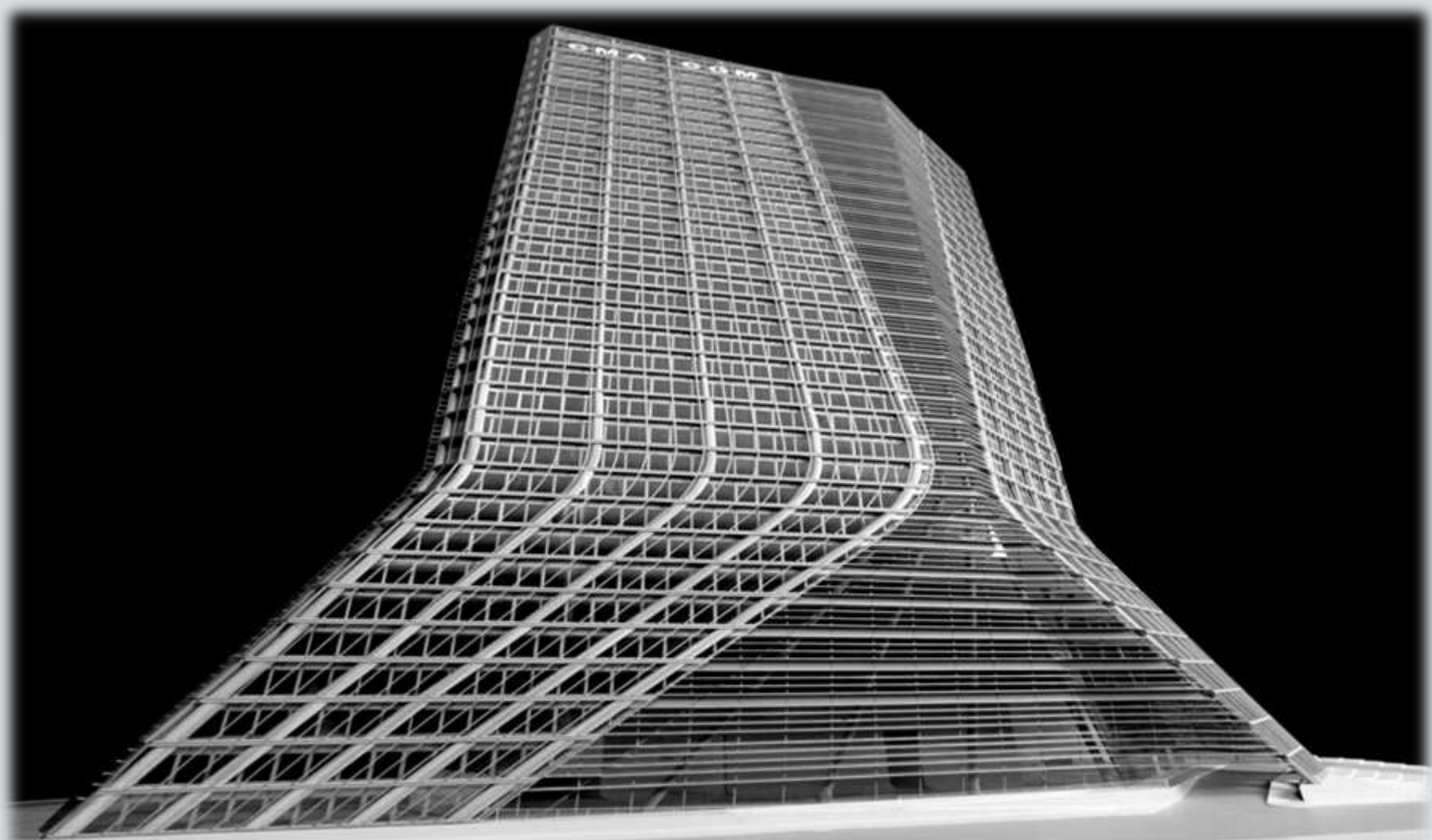


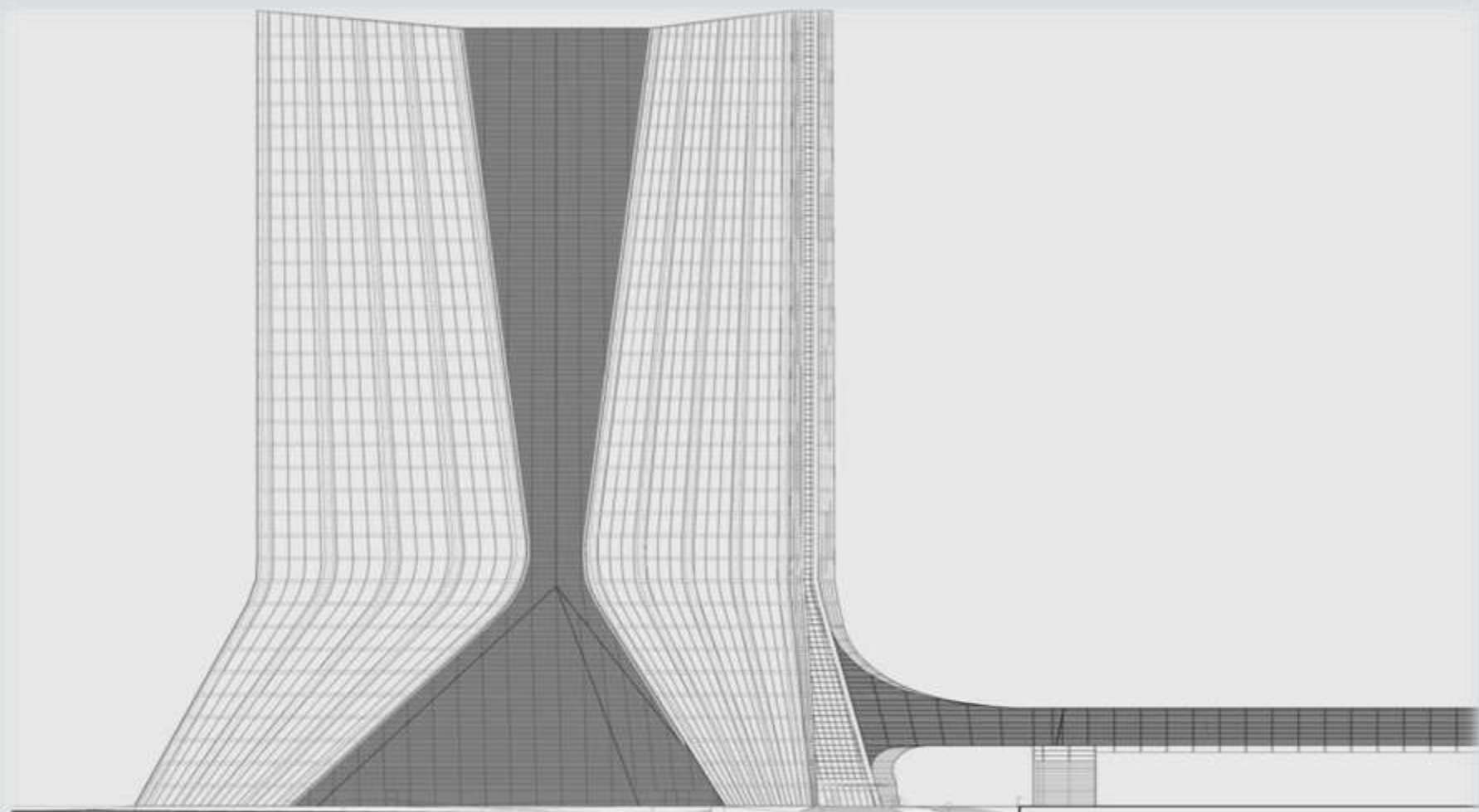
- ▶ Equilíbrio ( $\sum F_{x,y,z} = 0 + \sum M_{x,y,z} = 0$ )

# **Análise Estrutural**

- ▶ Estrutura Real
- ▶ Modelo Estrutural
- ▶ Modelo Discreto
- ▶ Modelo Computacional







WEST ELEVATION





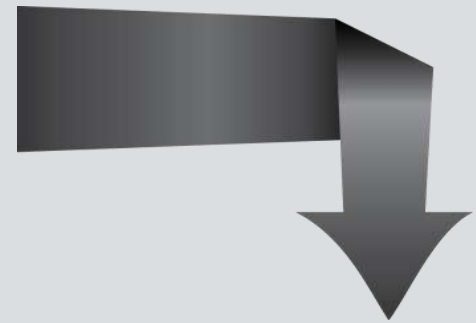


# Tipos de Análise Estrutural

- ▶ Análise Estática
- ▶ Análise Dinâmica
  
- ▶ Análise Linear
- ▶ Análise Não Linear

# Sequência da Análise

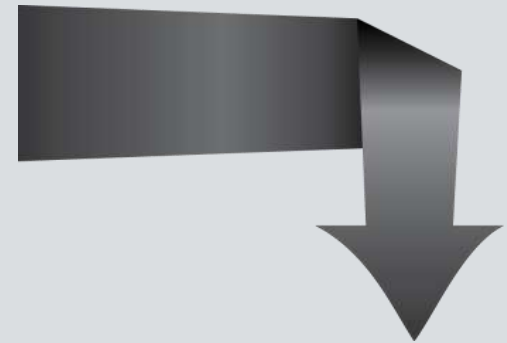
- ▶ Geometria da Estrutura
- ▶ Tipos de Elementos Estruturais
- ▶ Cargas
- ▶ Apoios (Boundary Conditions)
- ▶ Propriedades dos Materiais ...



- ▶ Deslocamentos
- ▶ Deformações
- ▶ Reações
- ▶ Tensões

# Hipóteses

- ▶ Aproximação Geométrica
- ▶ Cargas Estáticas e Cargas Dinâmicas
- ▶ Conexão dos Elementos
- ▶ Condição de Contorno
- ▶ Propriedades dos Materiais ...



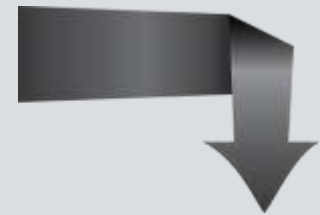
- ▶ Solução Aproximada

# Cálculo Analítico x Método Numérico

- ▶ Cálculo Analítico
- ▶ Resposta Exata ...

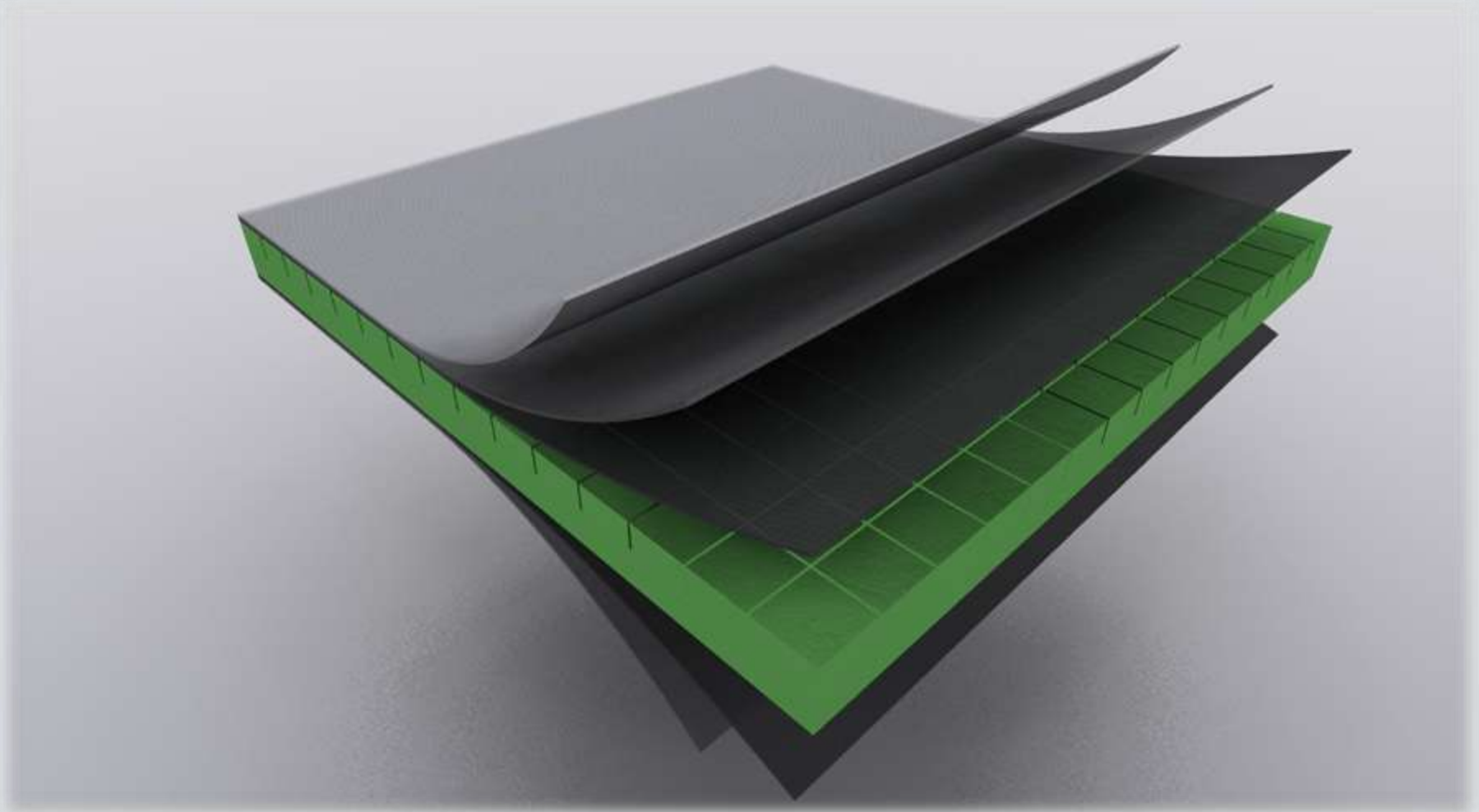


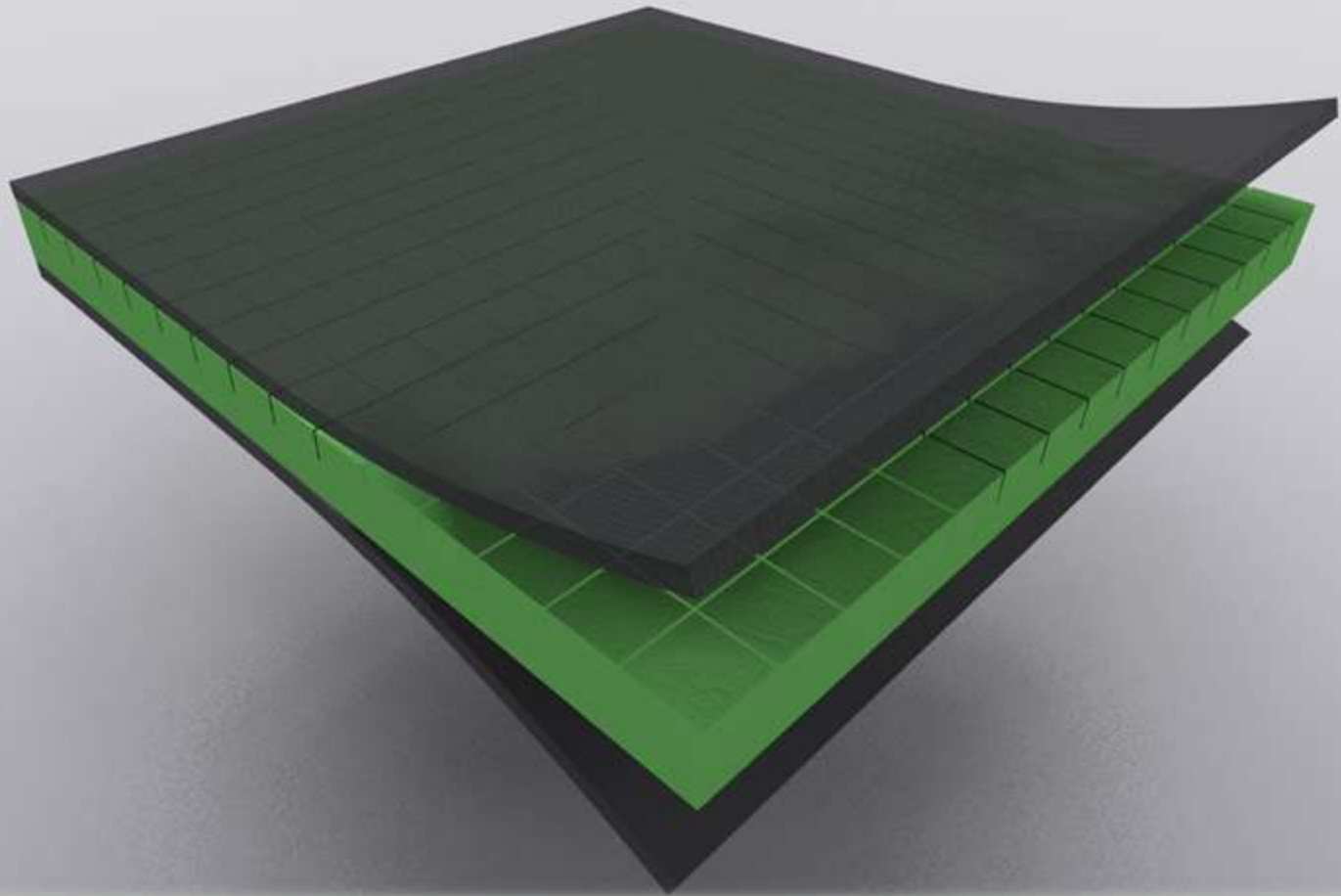
- ▶ Teoria das Superposições ...

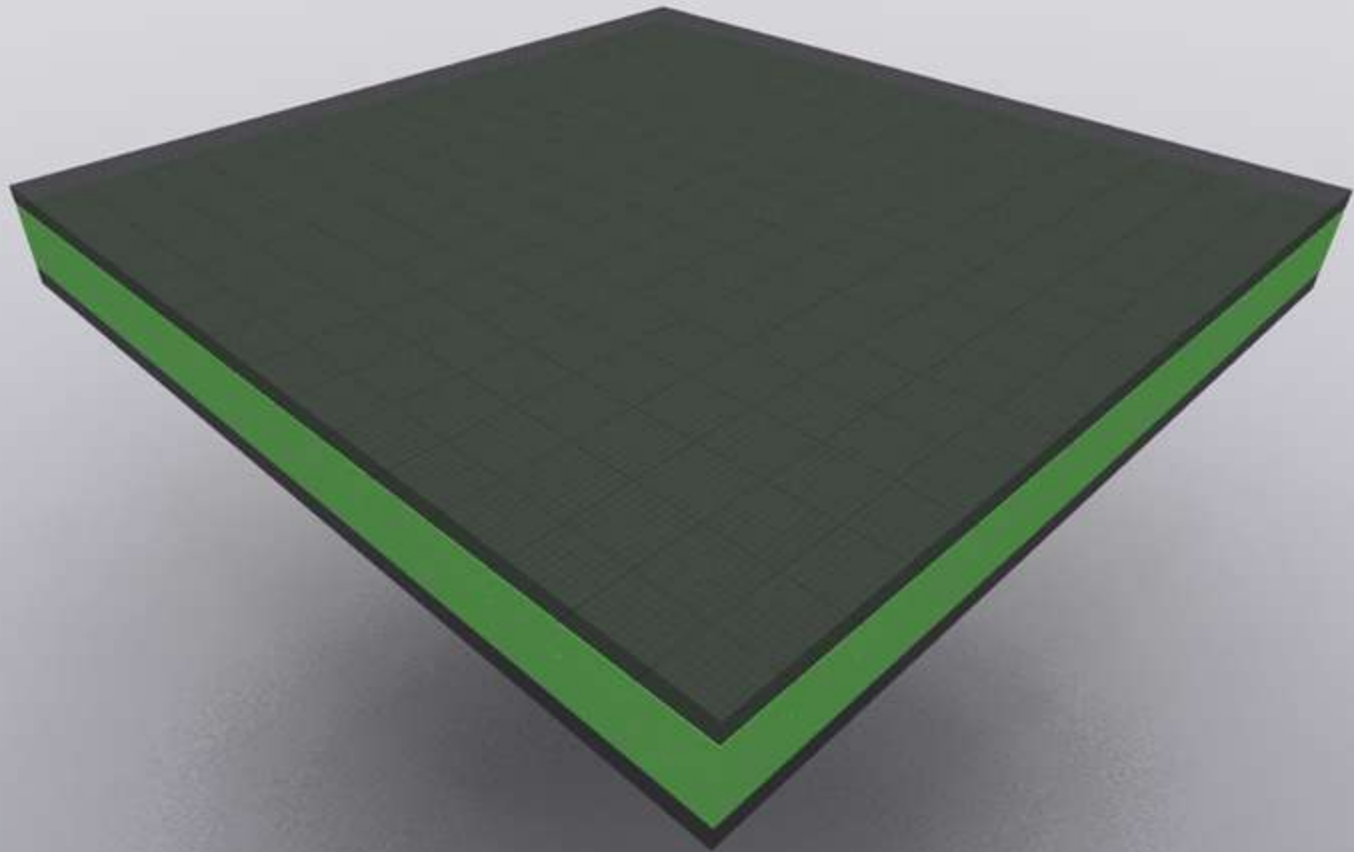


- ▶ Método Numérico
- ▶ Resposta Aproximada

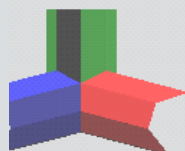
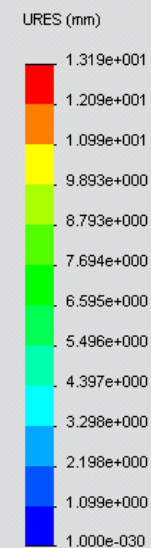
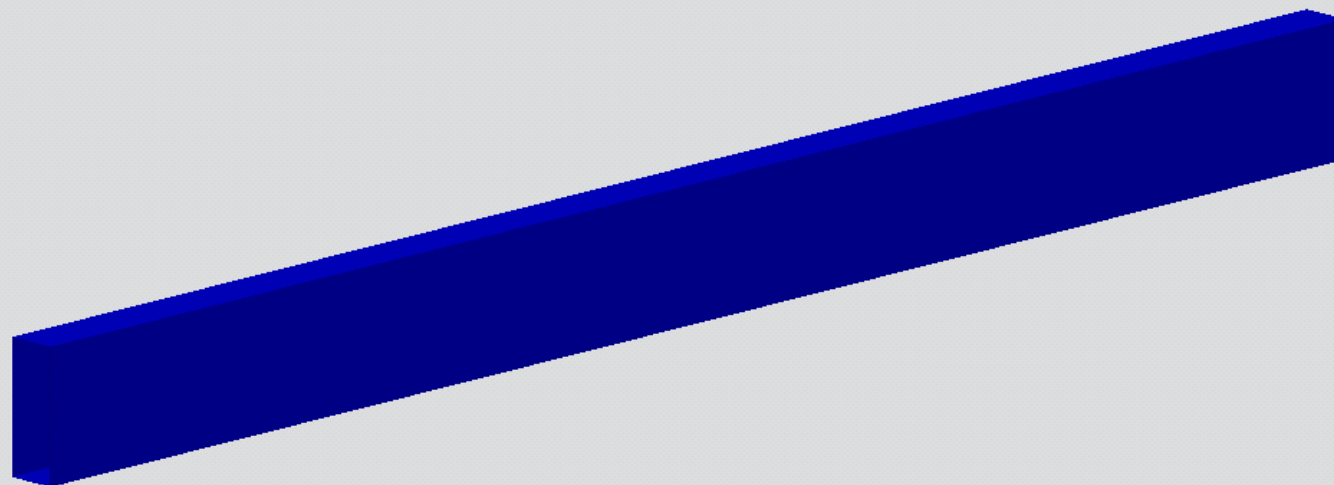




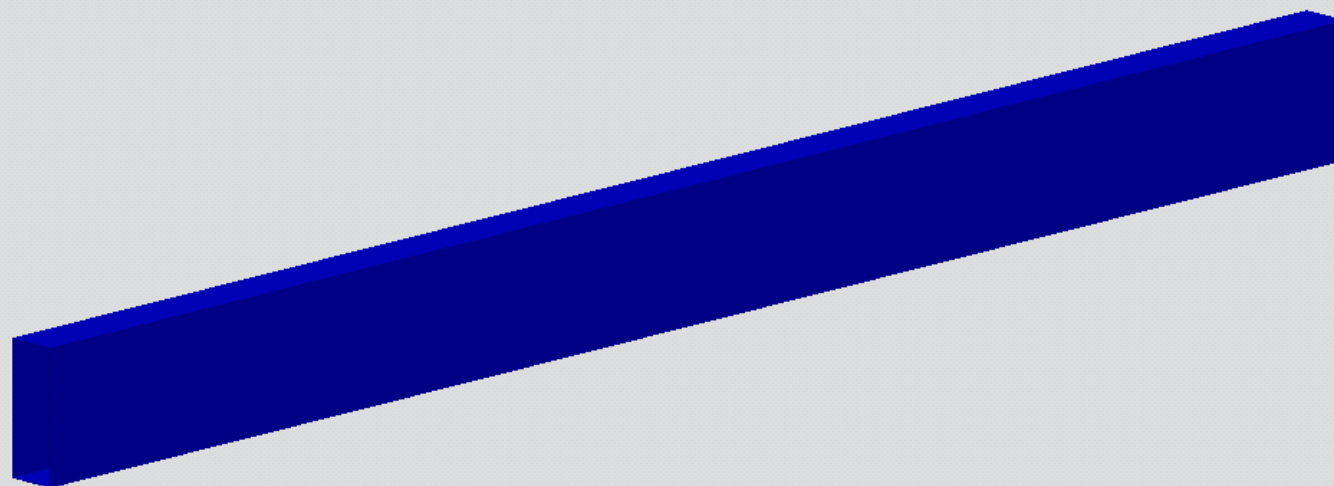




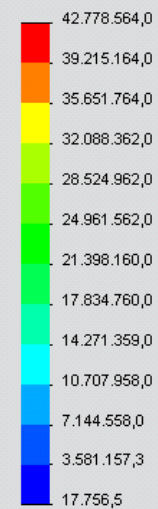




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Nome do estudo: Estudo 1  
Tipo de plotagem: Deslocamento estático Deslocamento1  
Escala de distorção: 75.918

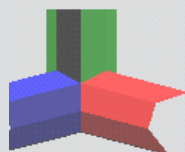


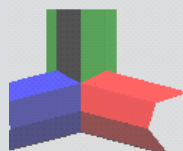
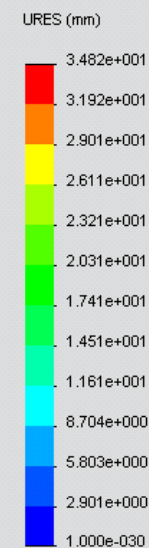
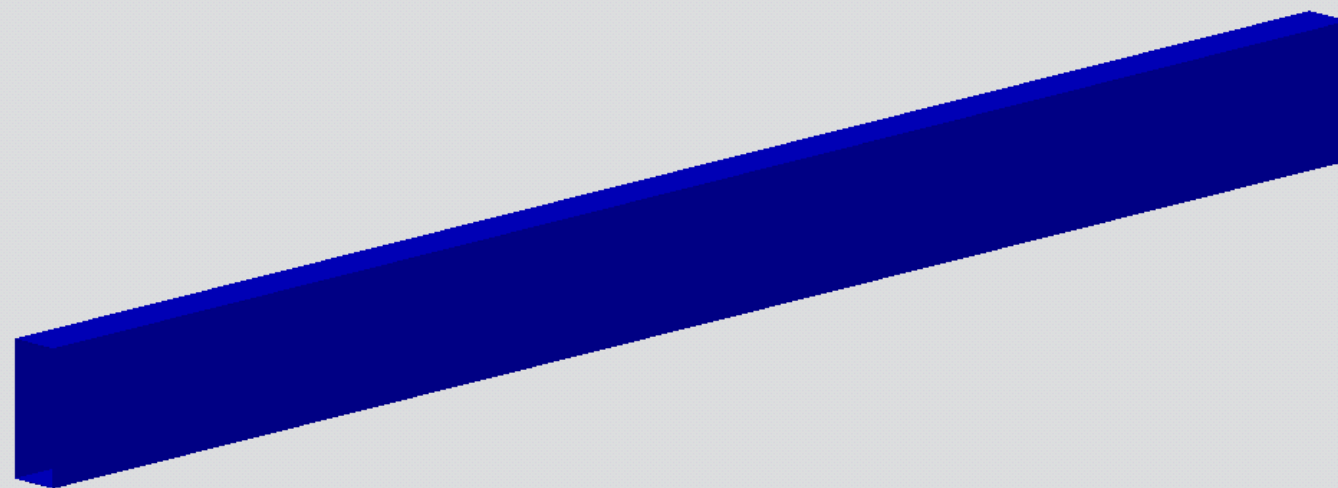
von Mises (N/m<sup>2</sup>)



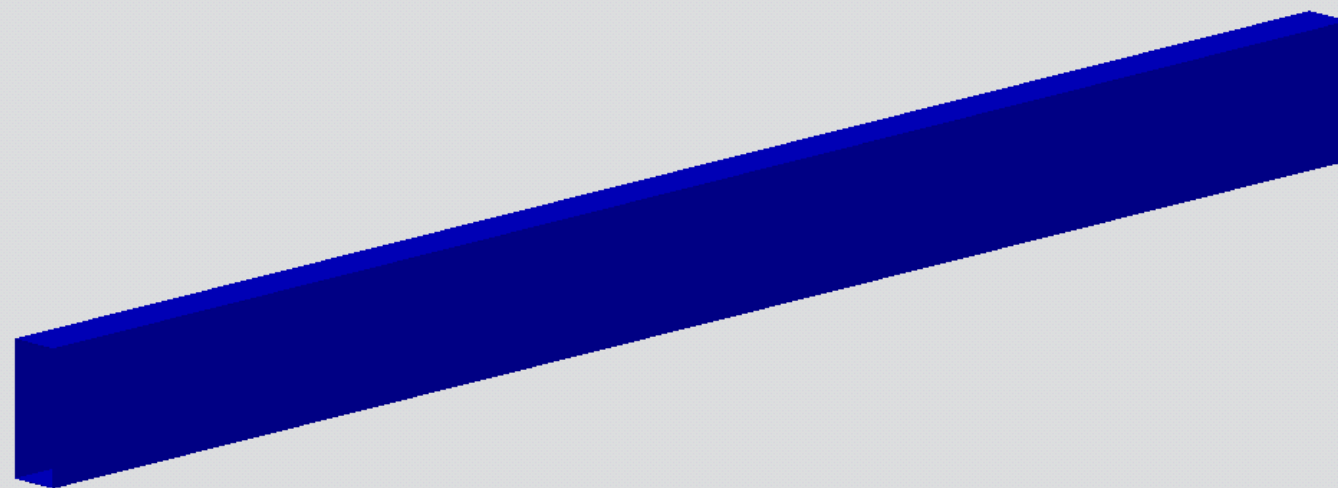
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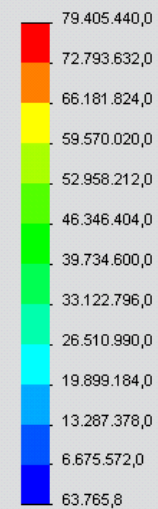




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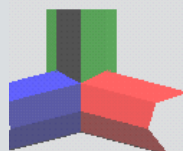


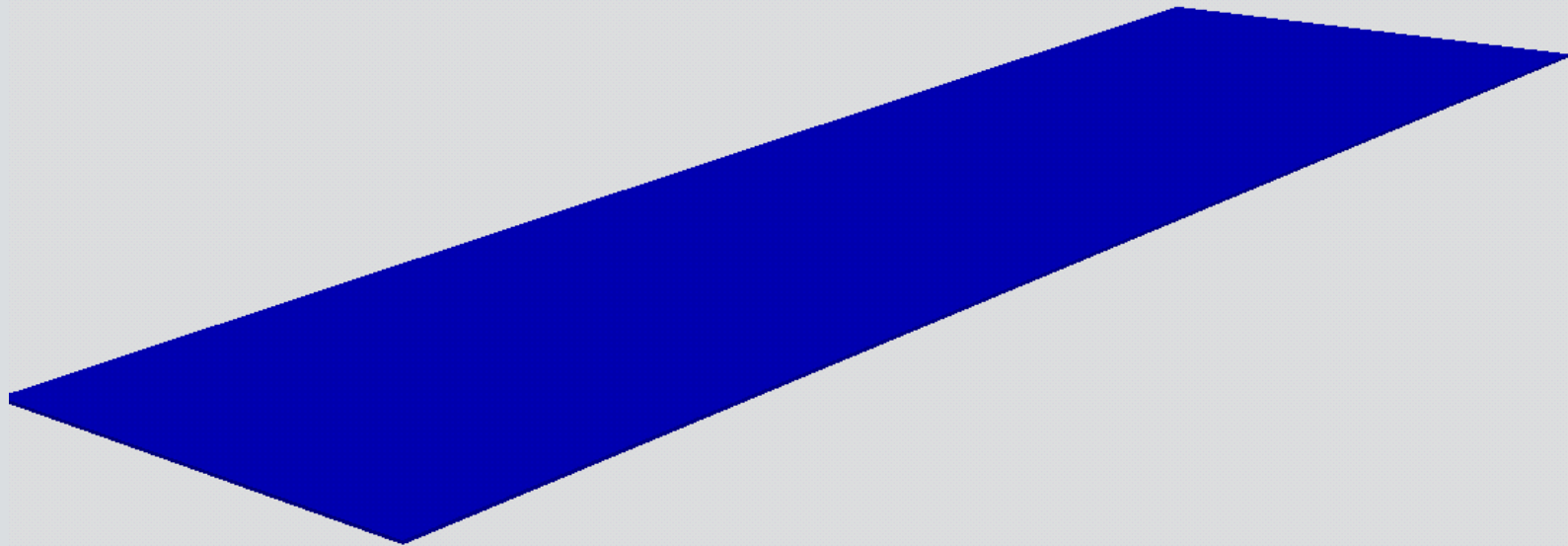
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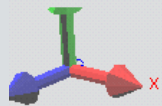
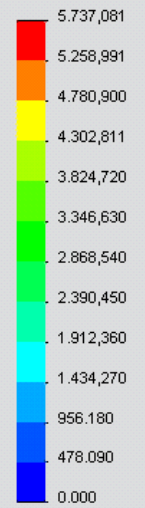
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Tipo de plotagem: Estático tensão nodal Tensão1  
Escala de distorção: 30.9756

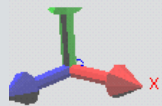
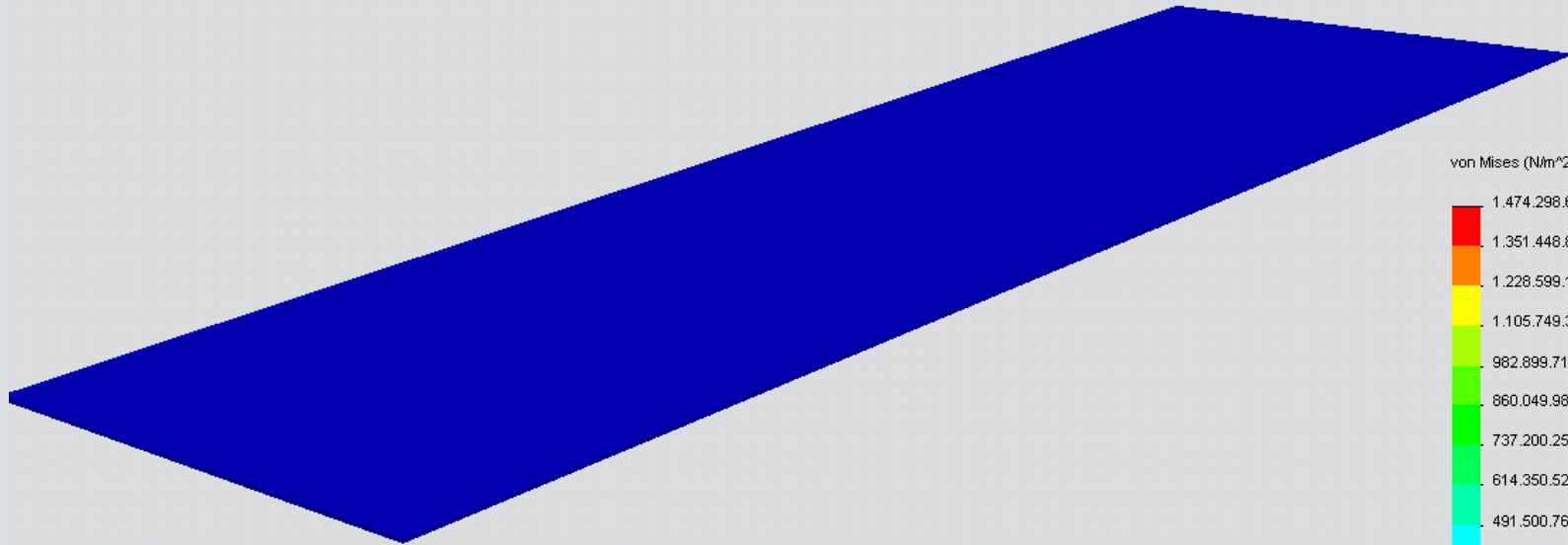




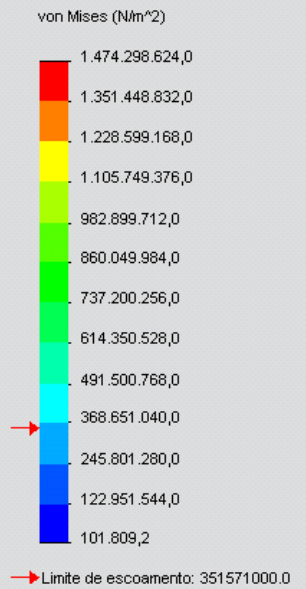
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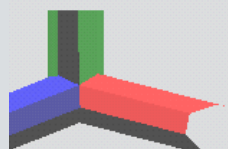
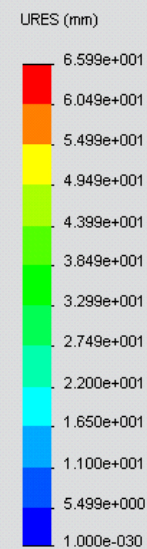
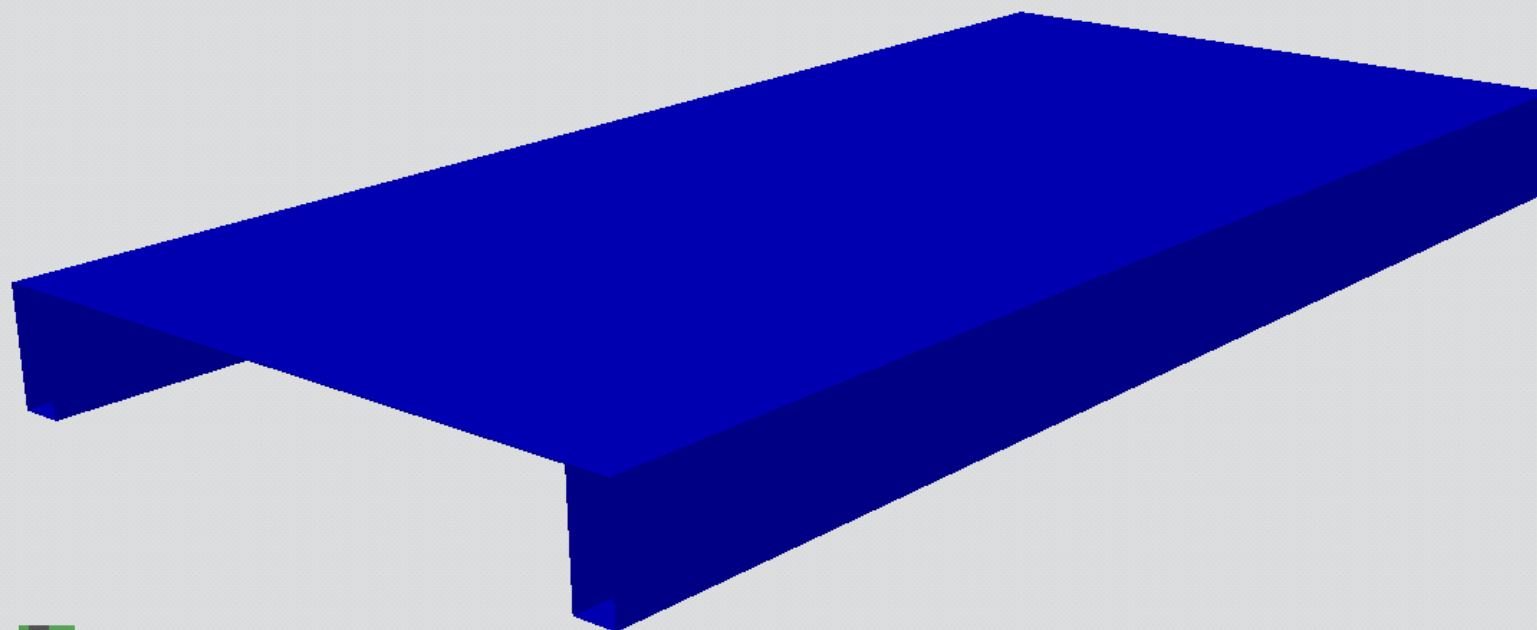


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Tipo de plotagem: Deslocamento estático Deslocamento1  
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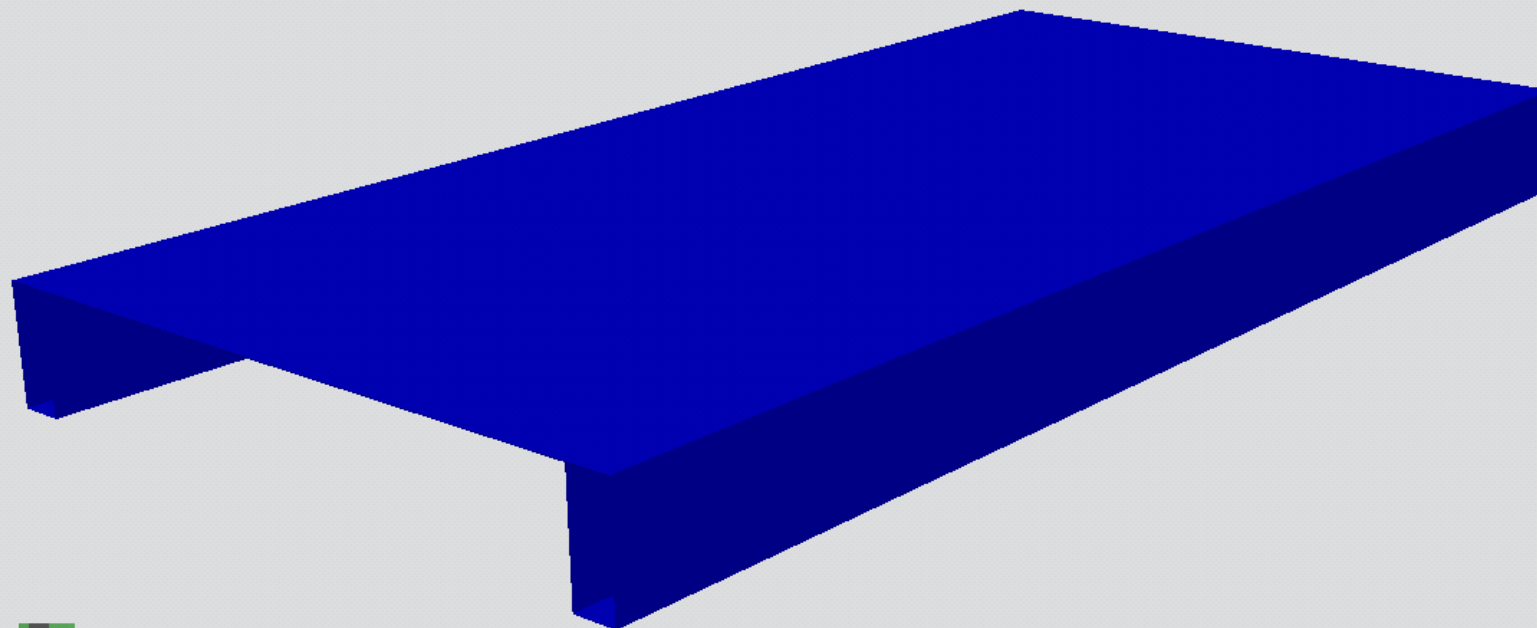


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Nome do estudo: Estudo 1  
Tipo de plotagem: Estático tensão nodal Tensão1  
Escala de distorção: 0.0522915

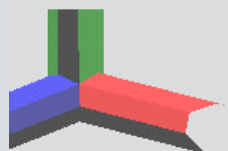




Nome do modelo: Vigas\_2011.08.17\_assembly  
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Tipo de plotagem: Deslocamento estático Deslocamento1  
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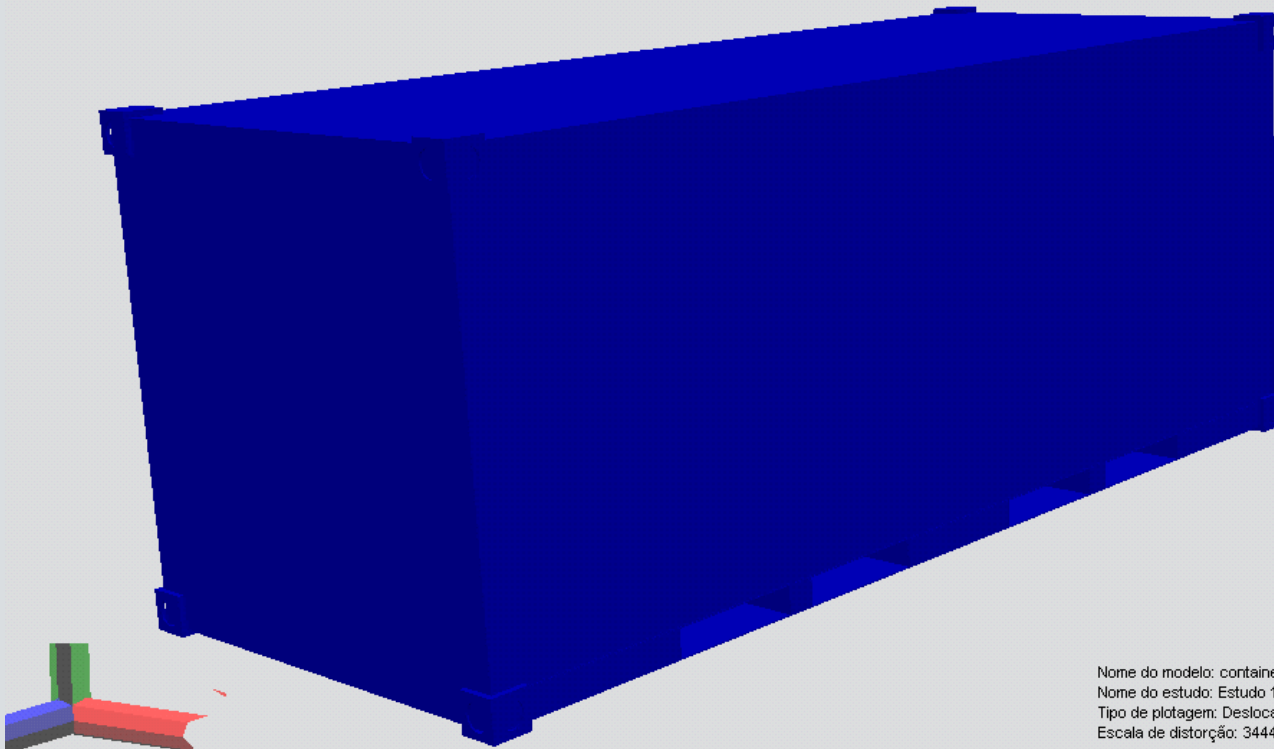


von Mises (N/m<sup>2</sup>)

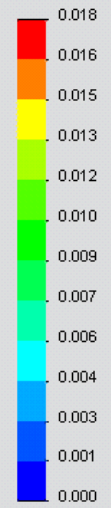


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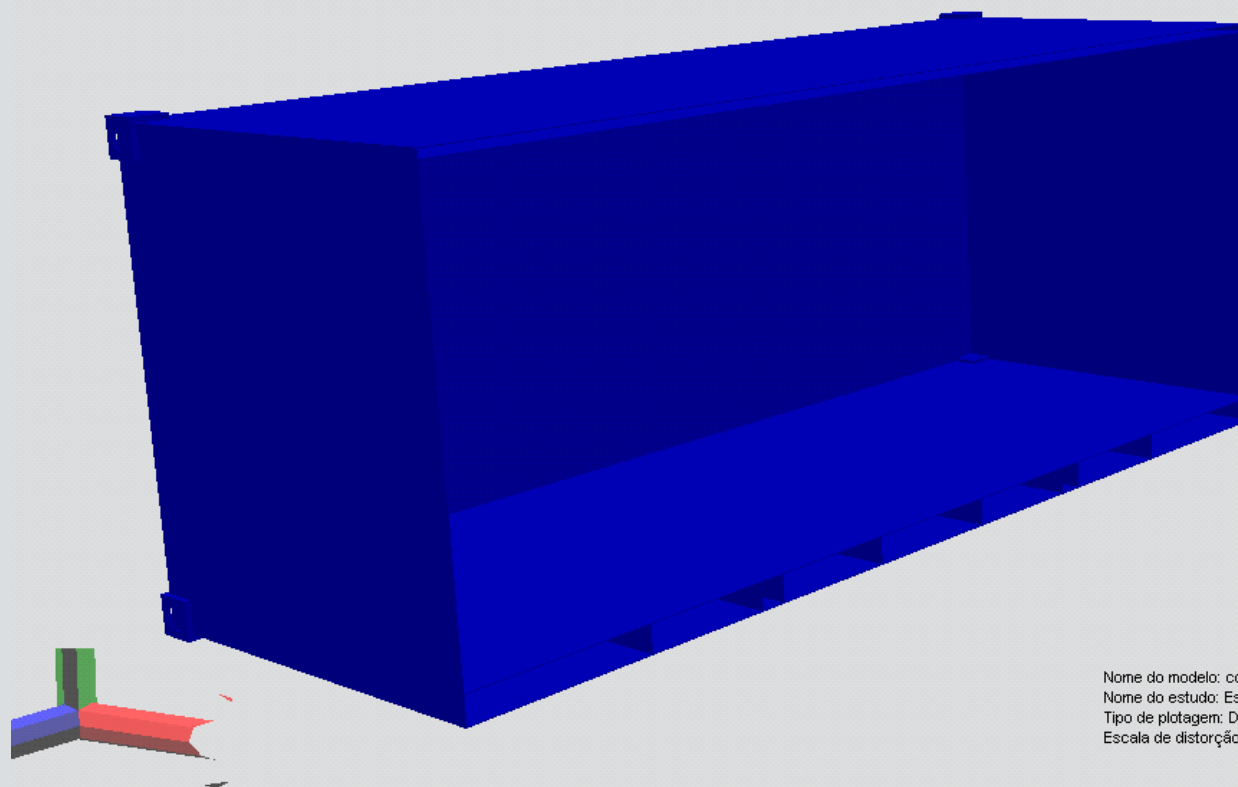




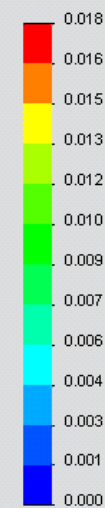
URES (mm)



Nome do modelo: container  
Nome do estudo: Estudo 1  
Tipo de plotagem: Deslocamento estático Deslocamento1  
Escala de distorção: 34442.8



URES (mm)



Nome do modelo: container  
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# Hipóteses para Análise Linear Estática

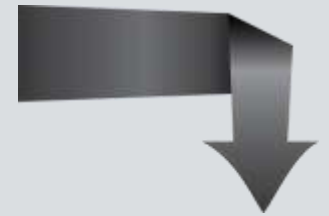
*Teoria da Elasticidade  
(Equações de Euler e Lei de Hooke)*

- ▶ Material é Elástico (Robert Hooke)
- ▶ Tensões são Proporcionais as Deformações
- ▶ Todas as Deformações são Pequenas (Infinitesimais)
- ▶ Alta Razão de Aspecto
- ▶ Material é Isotrópico

# Métodos Numéricos

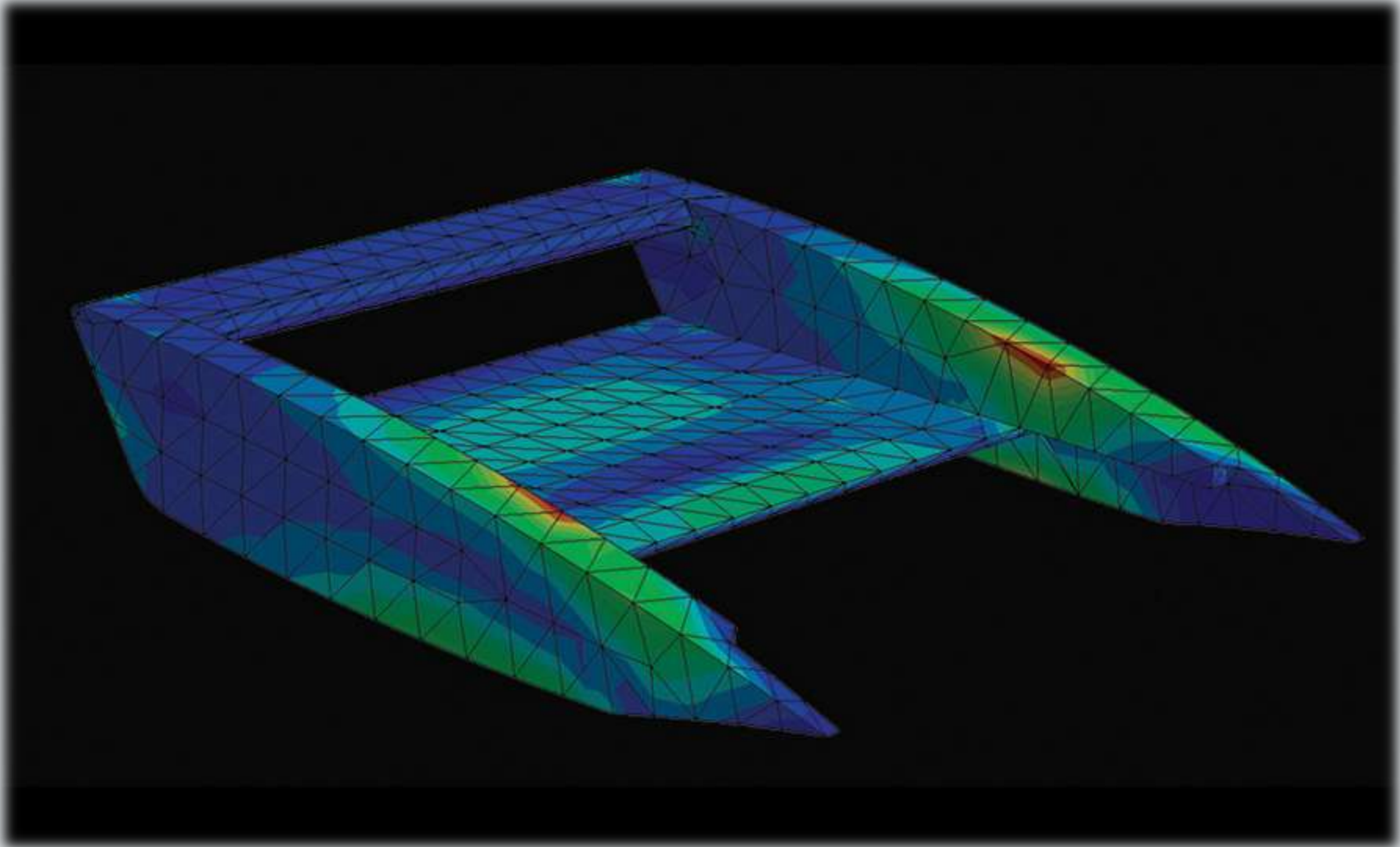
## Método dos Elementos Finitos

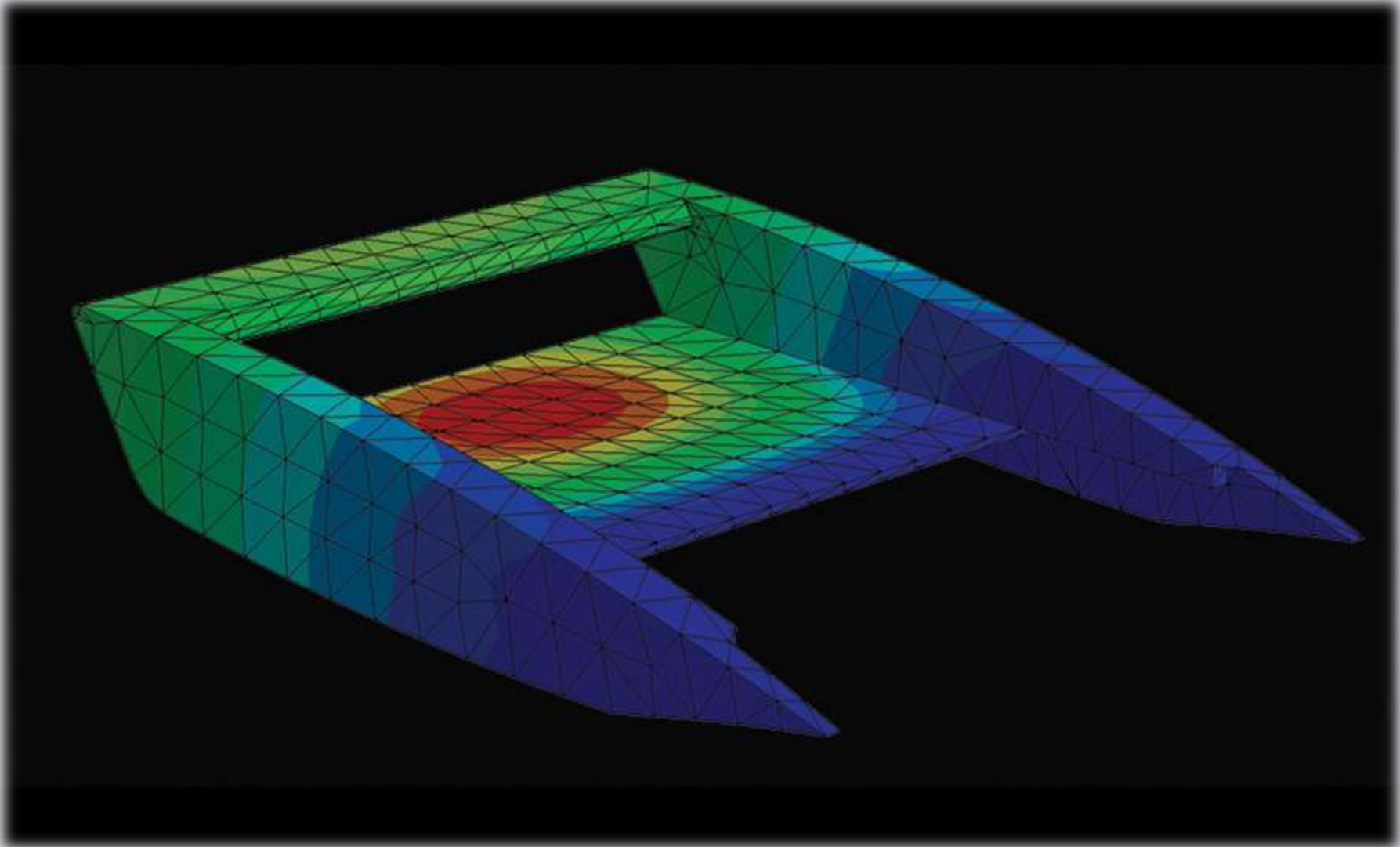
- ▶ Dividir a estrutura em pequenos elementos conhecidos
- ▶ Campo de Deslocamentos
- ▶ Elementos são conectados através de Nós
- ▶ Nós > Graus de Liberdade do Elemento
- ▶ Aplicar Forças
- ▶ Condições de Contorno ...

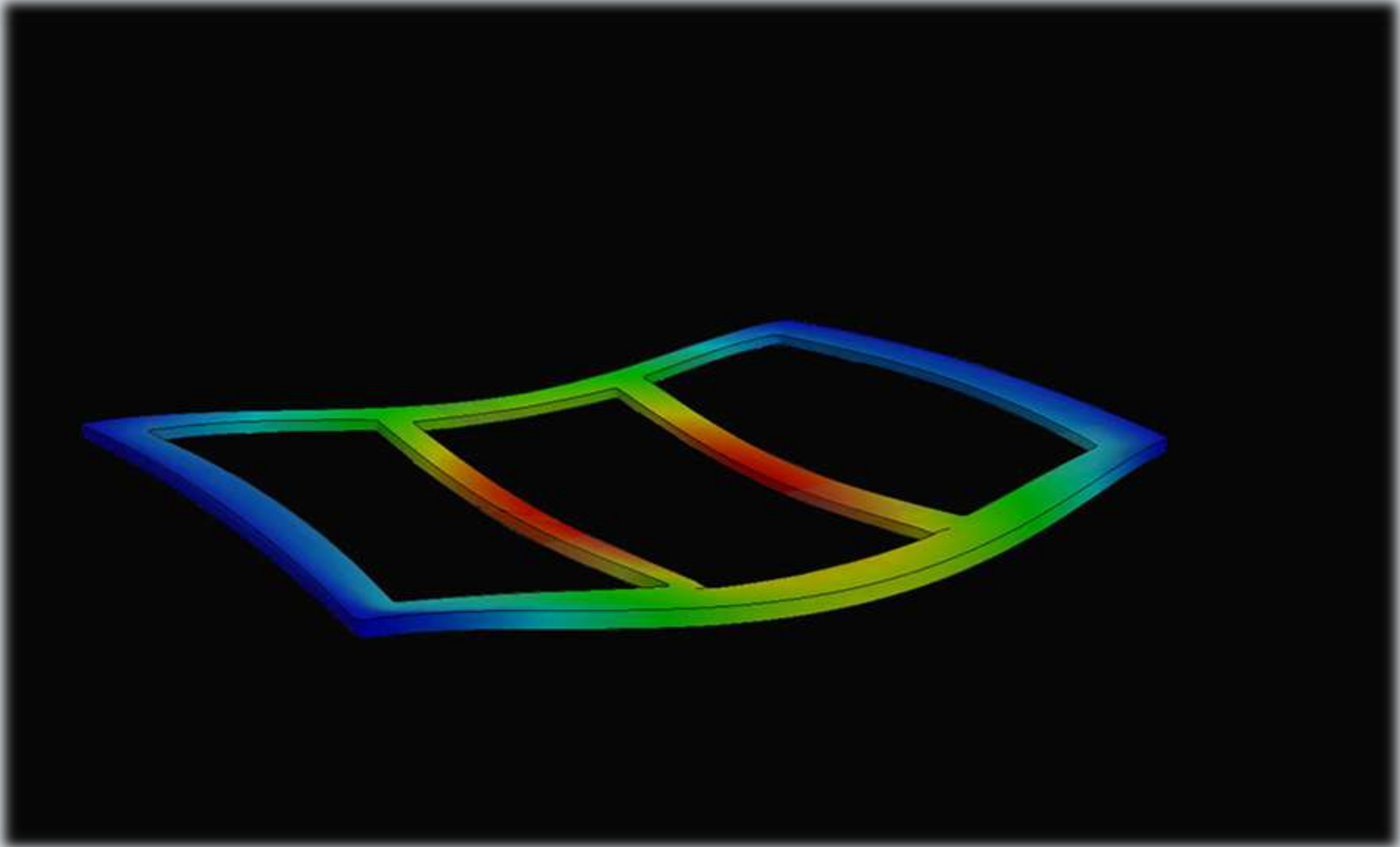


- ▶ Deslocamentos Nodais
- ▶ Deformações
- ▶ Forças Internas
- ▶ Tensões

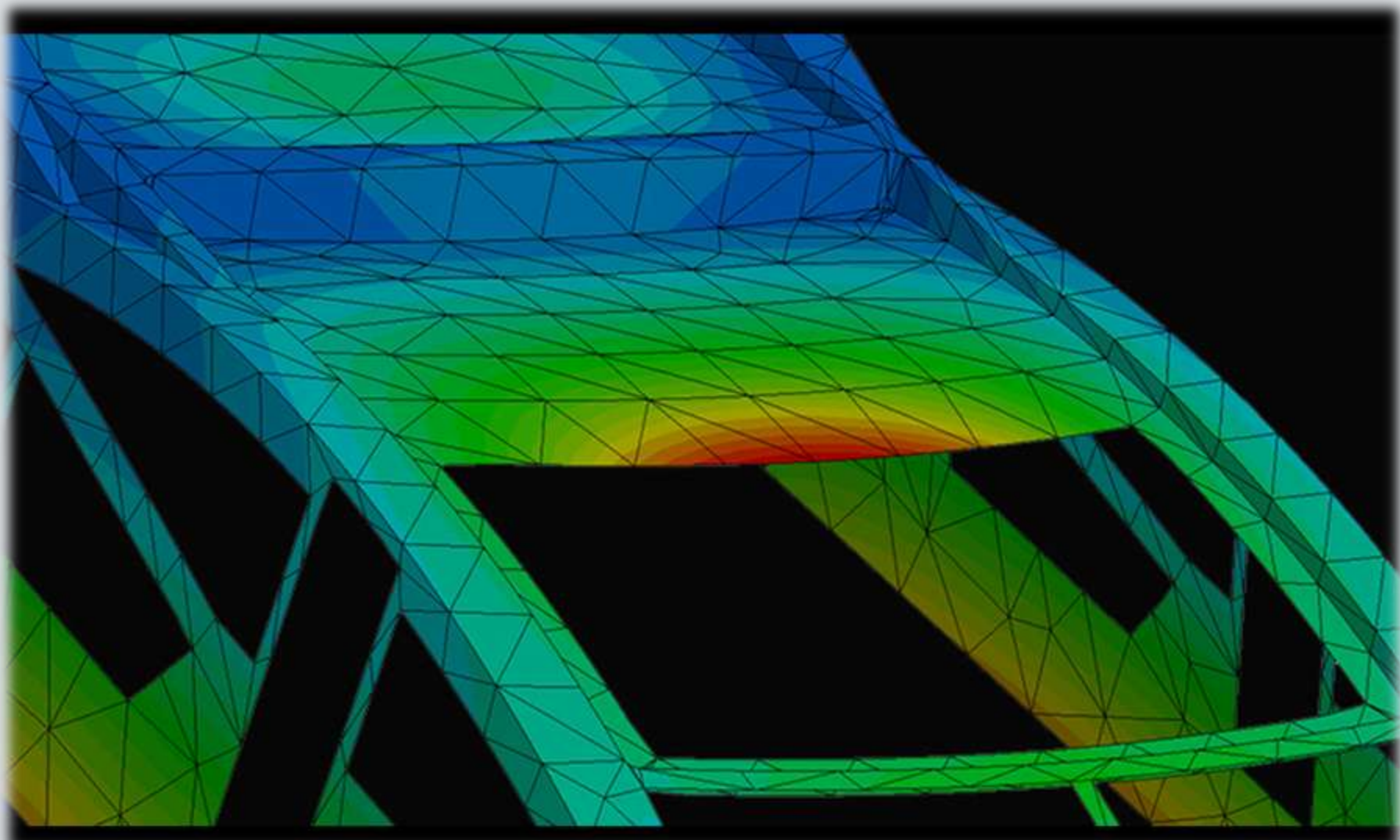
# **Exemplos de Análise**

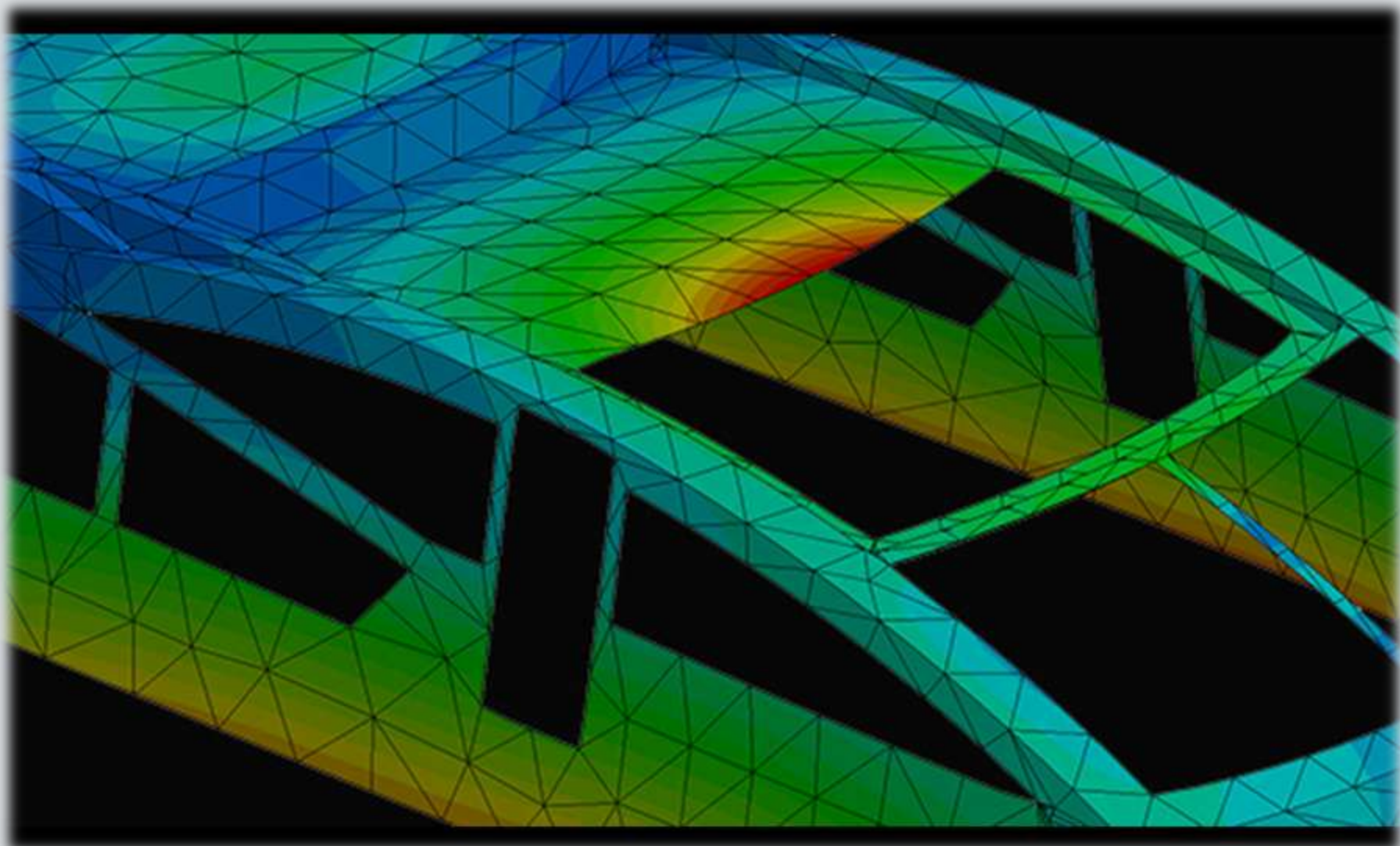


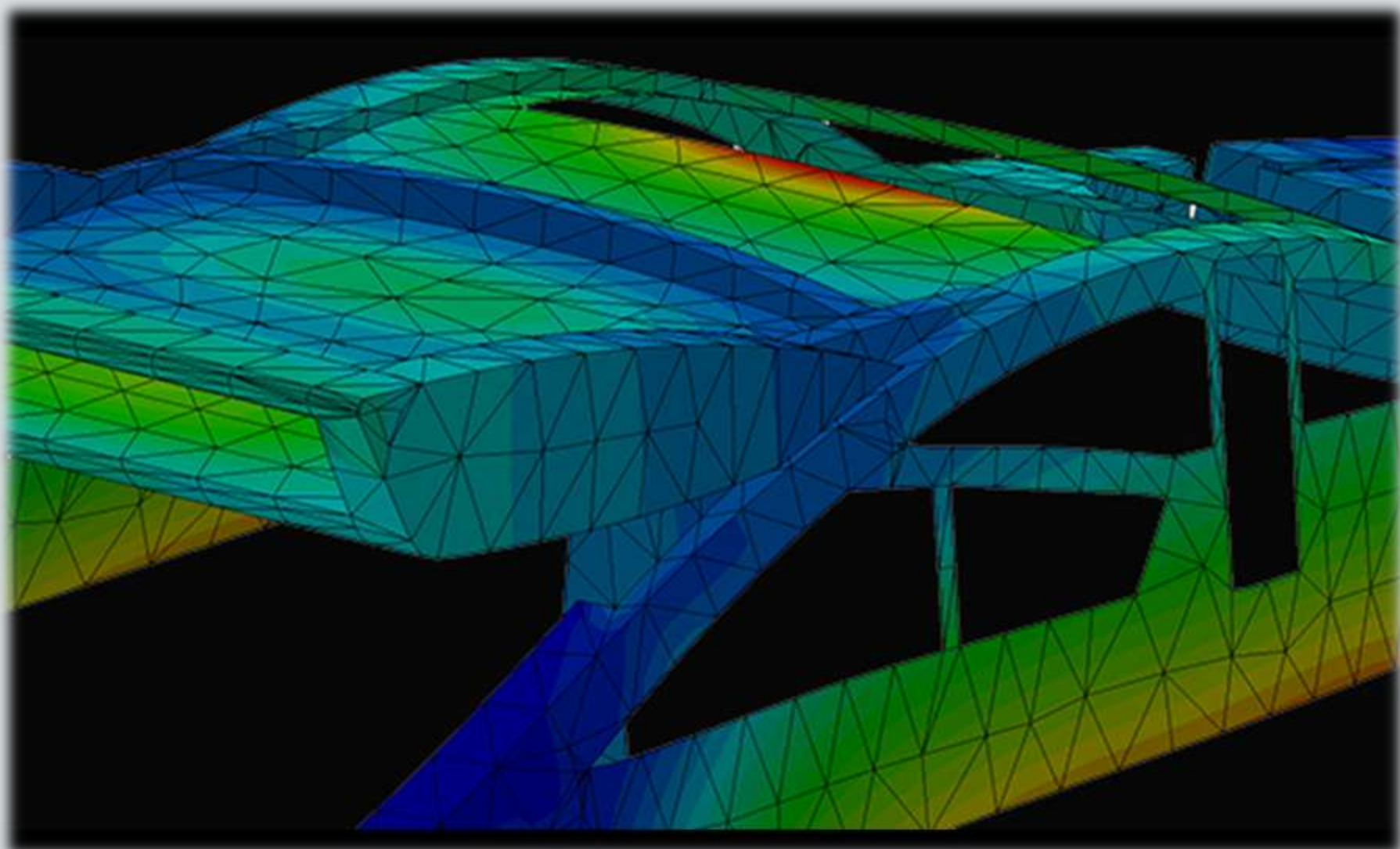


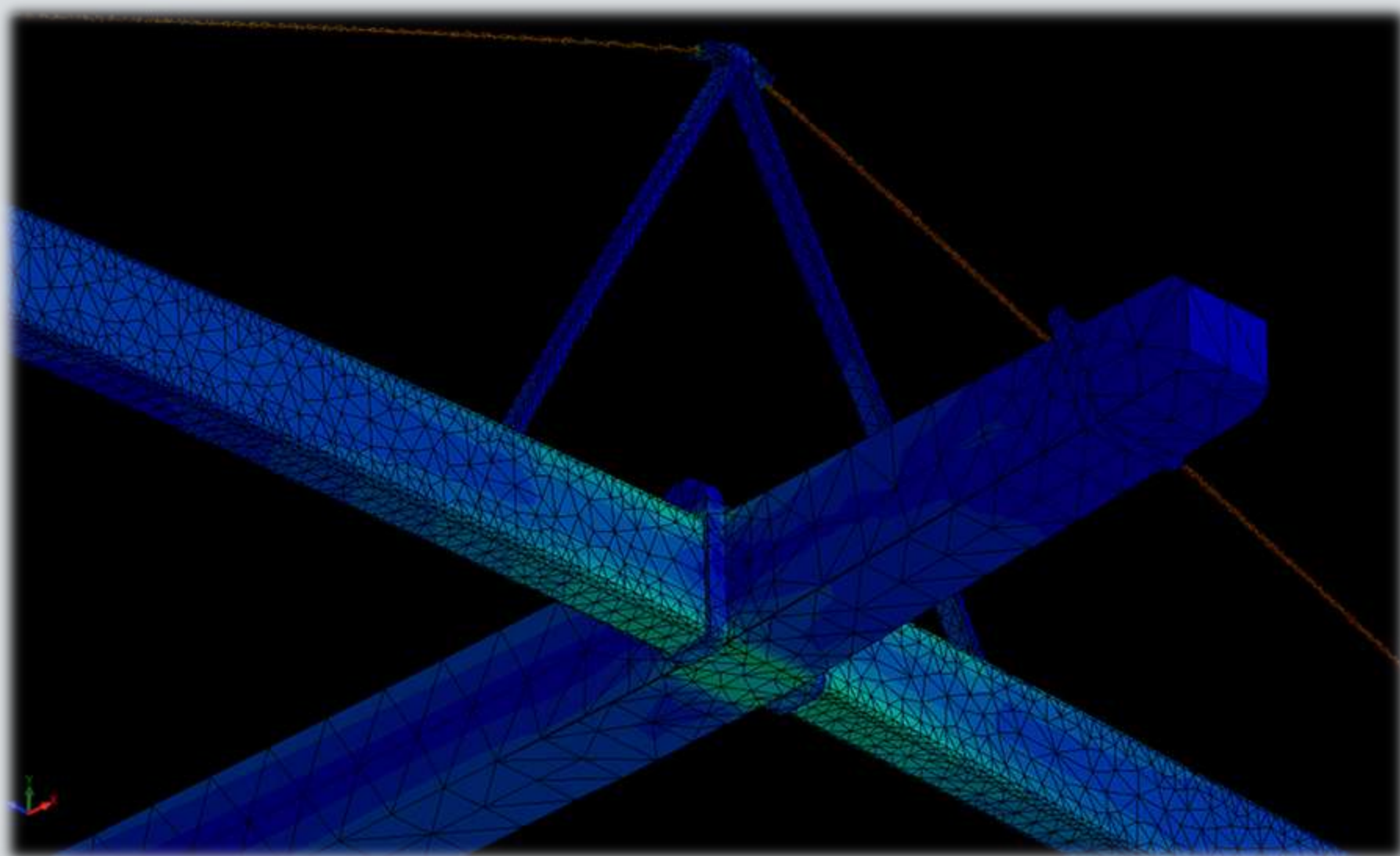


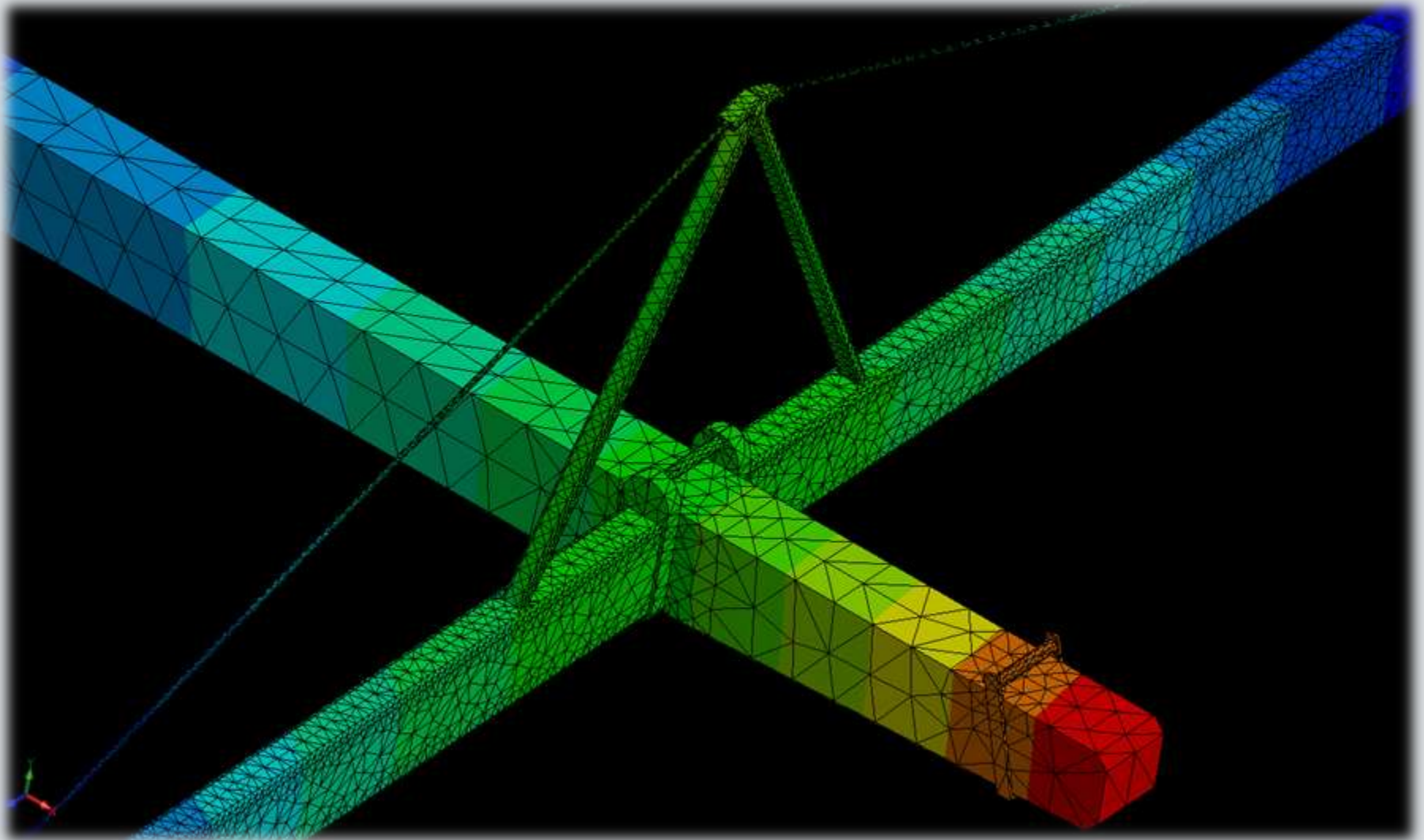


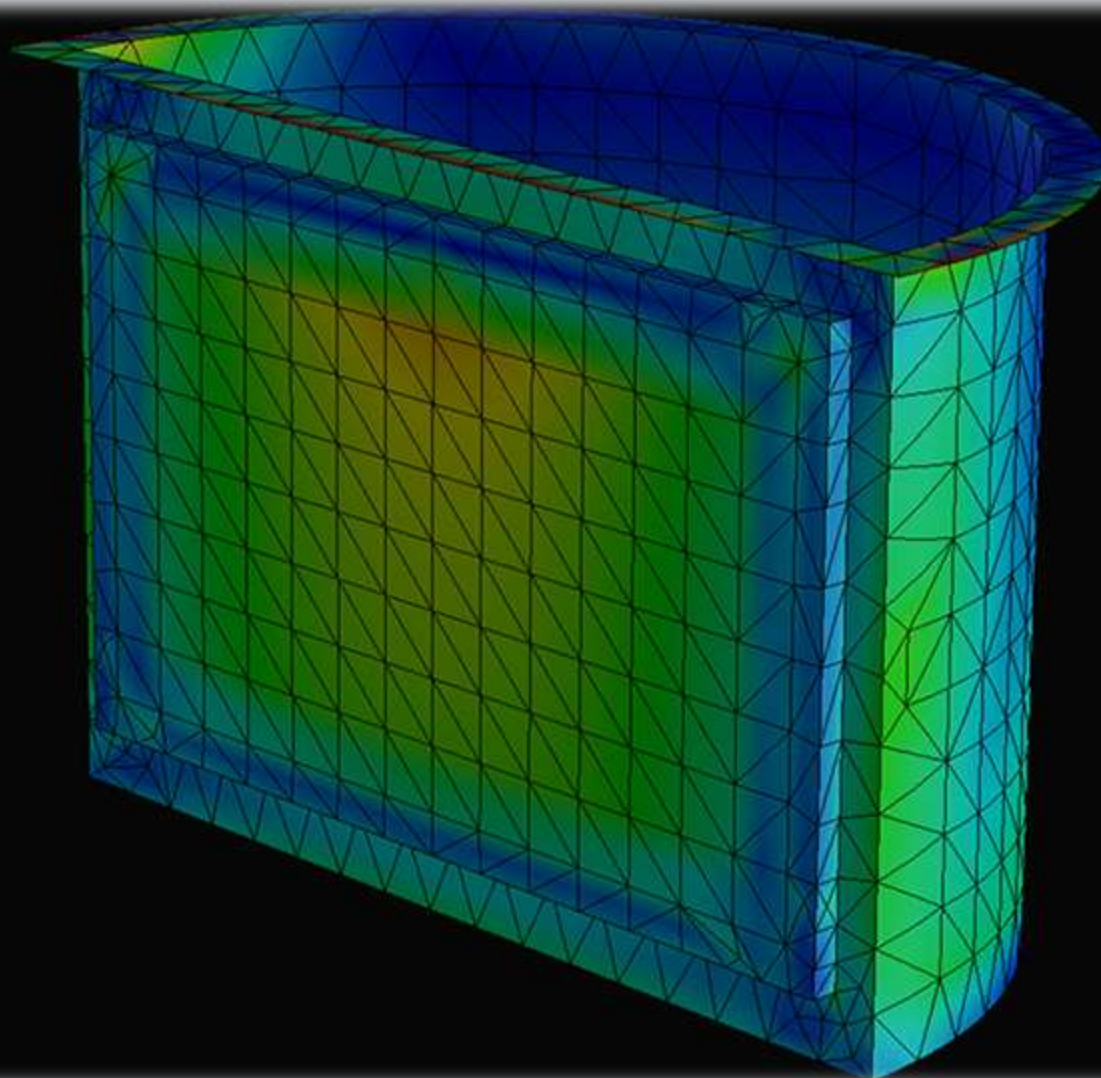


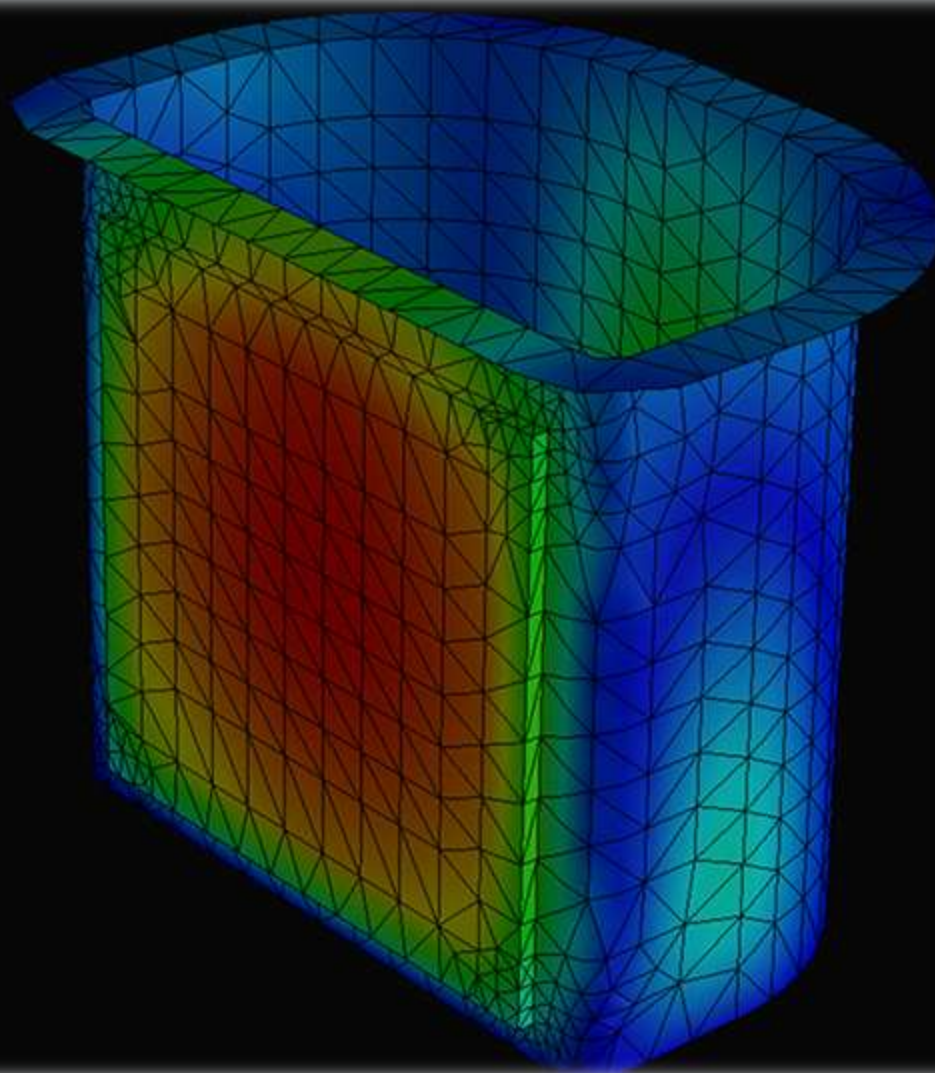


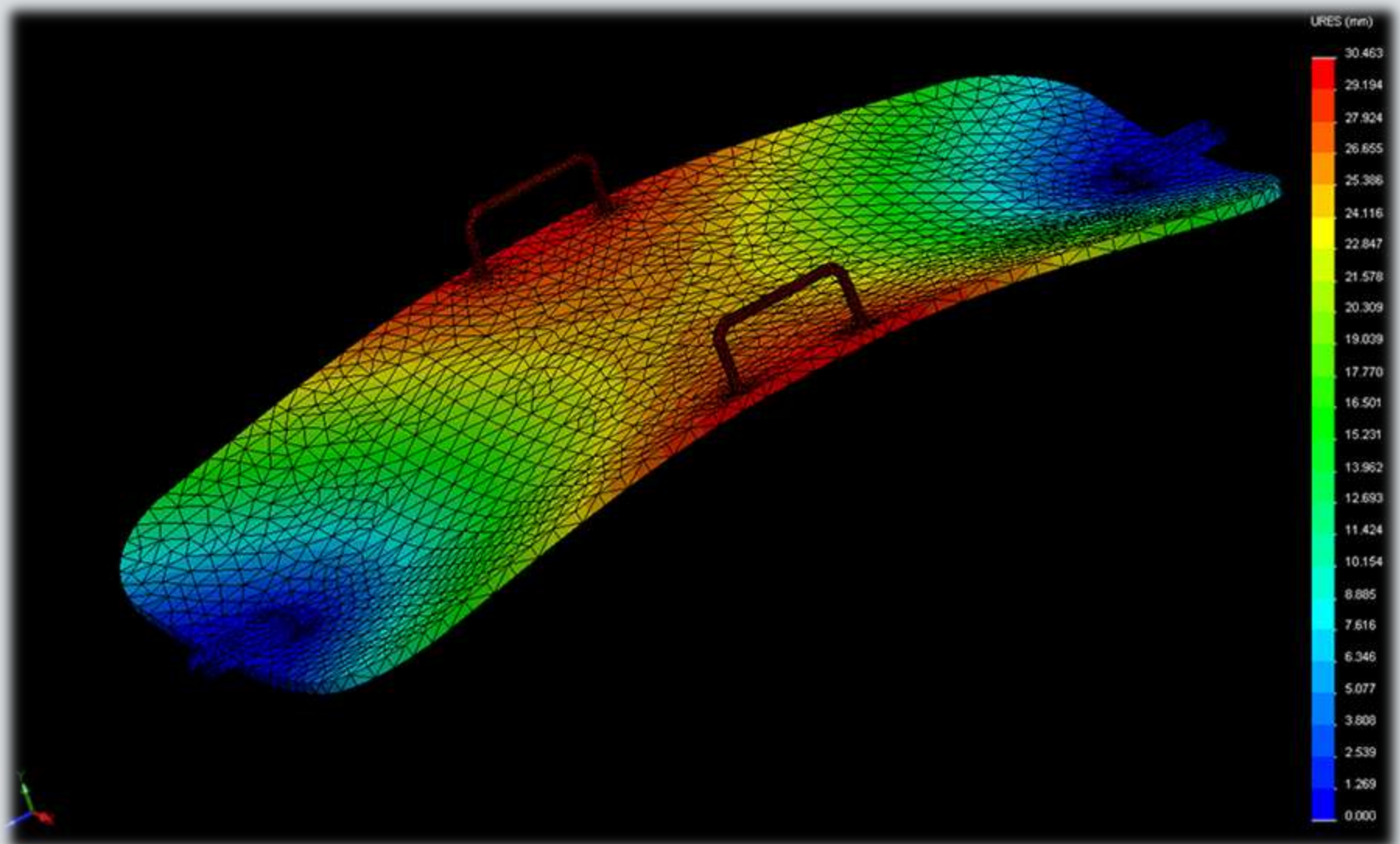




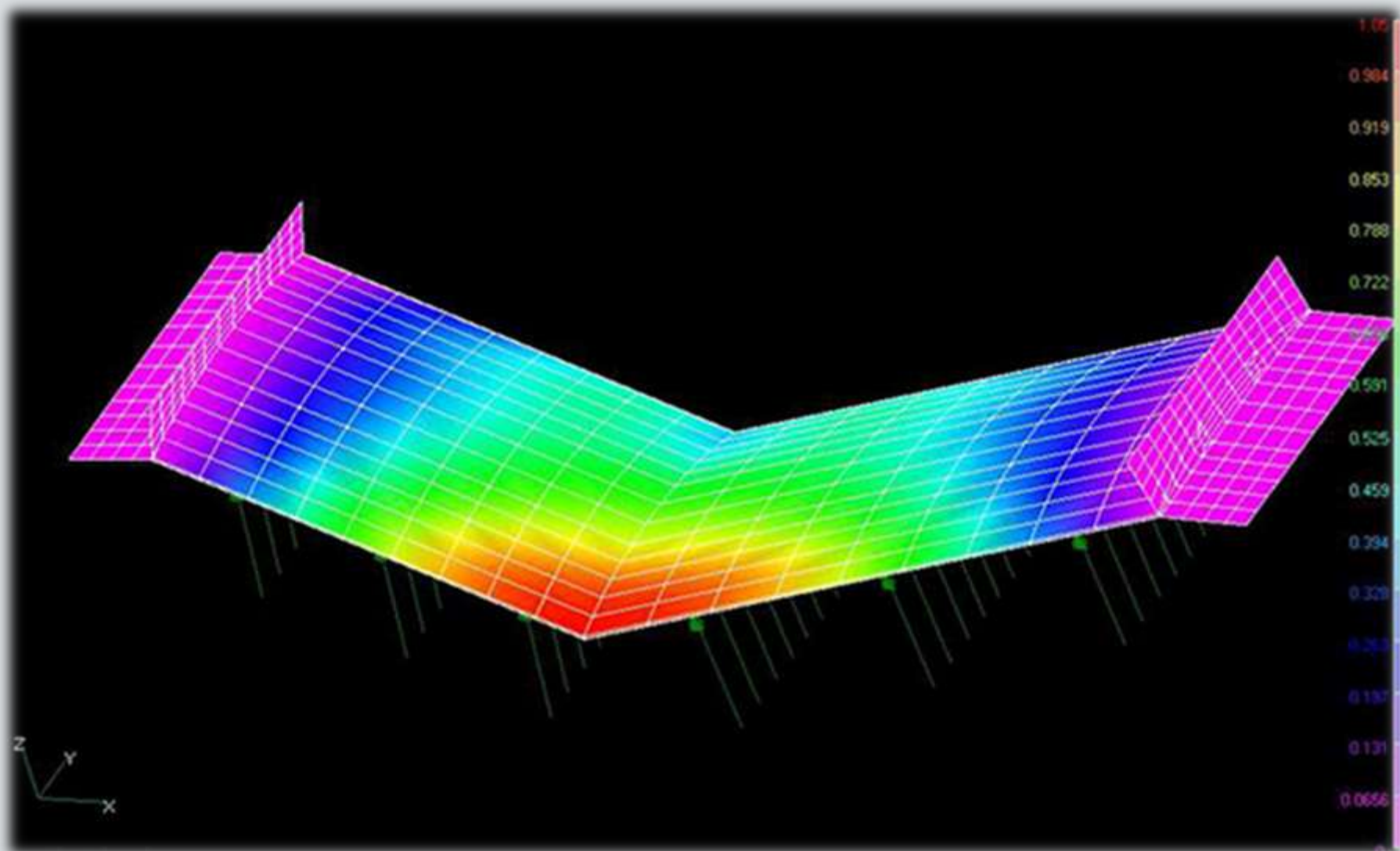


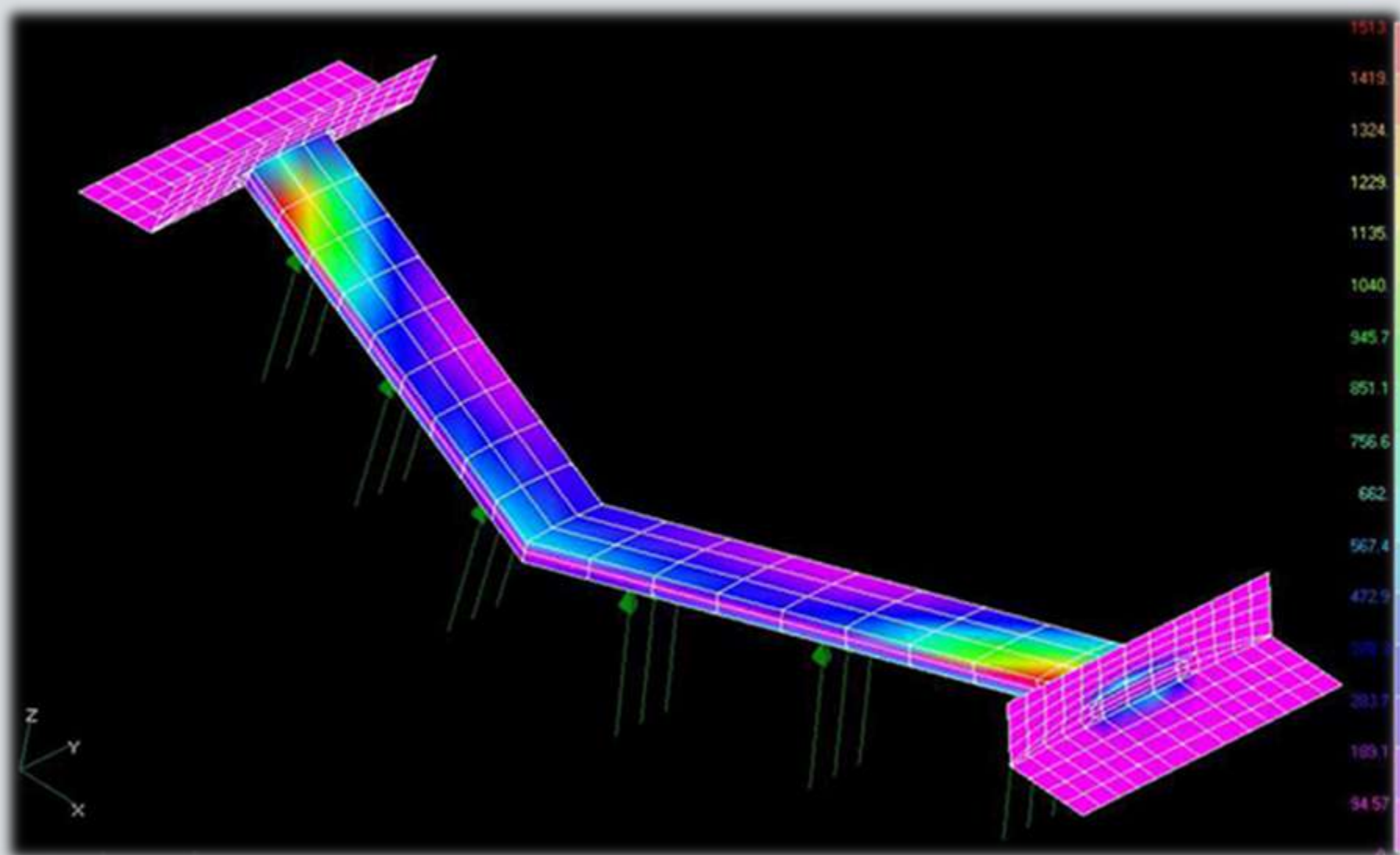


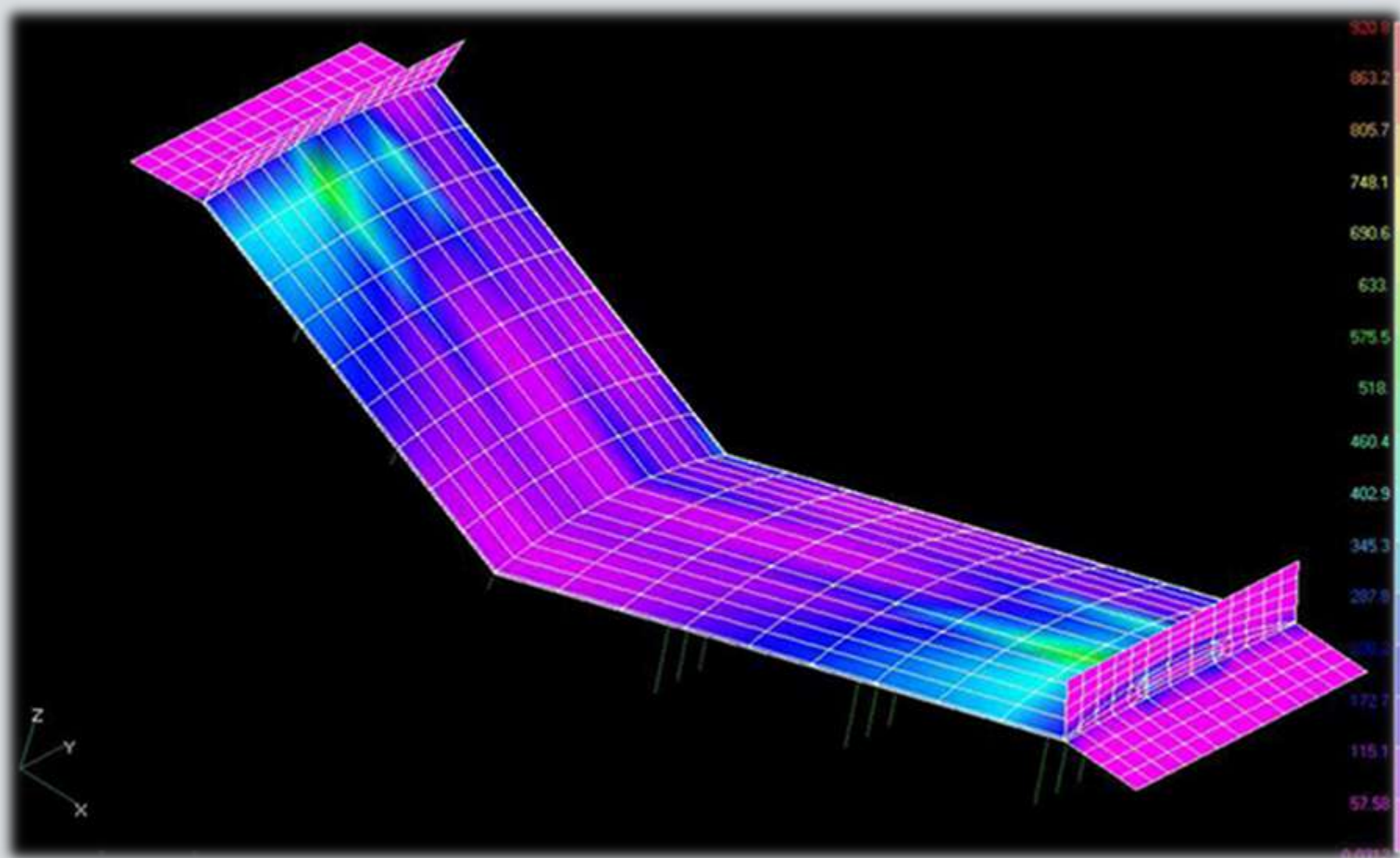


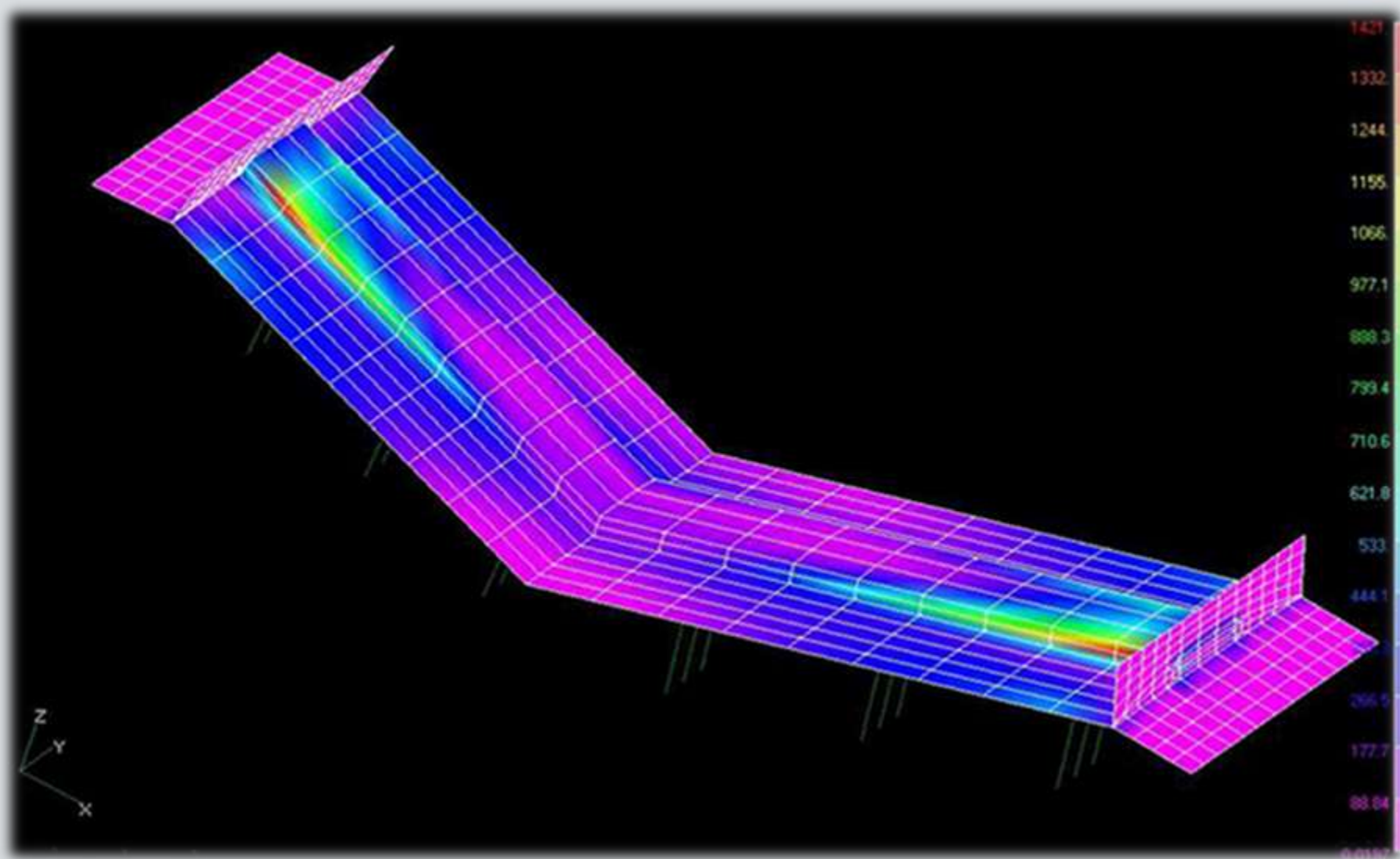


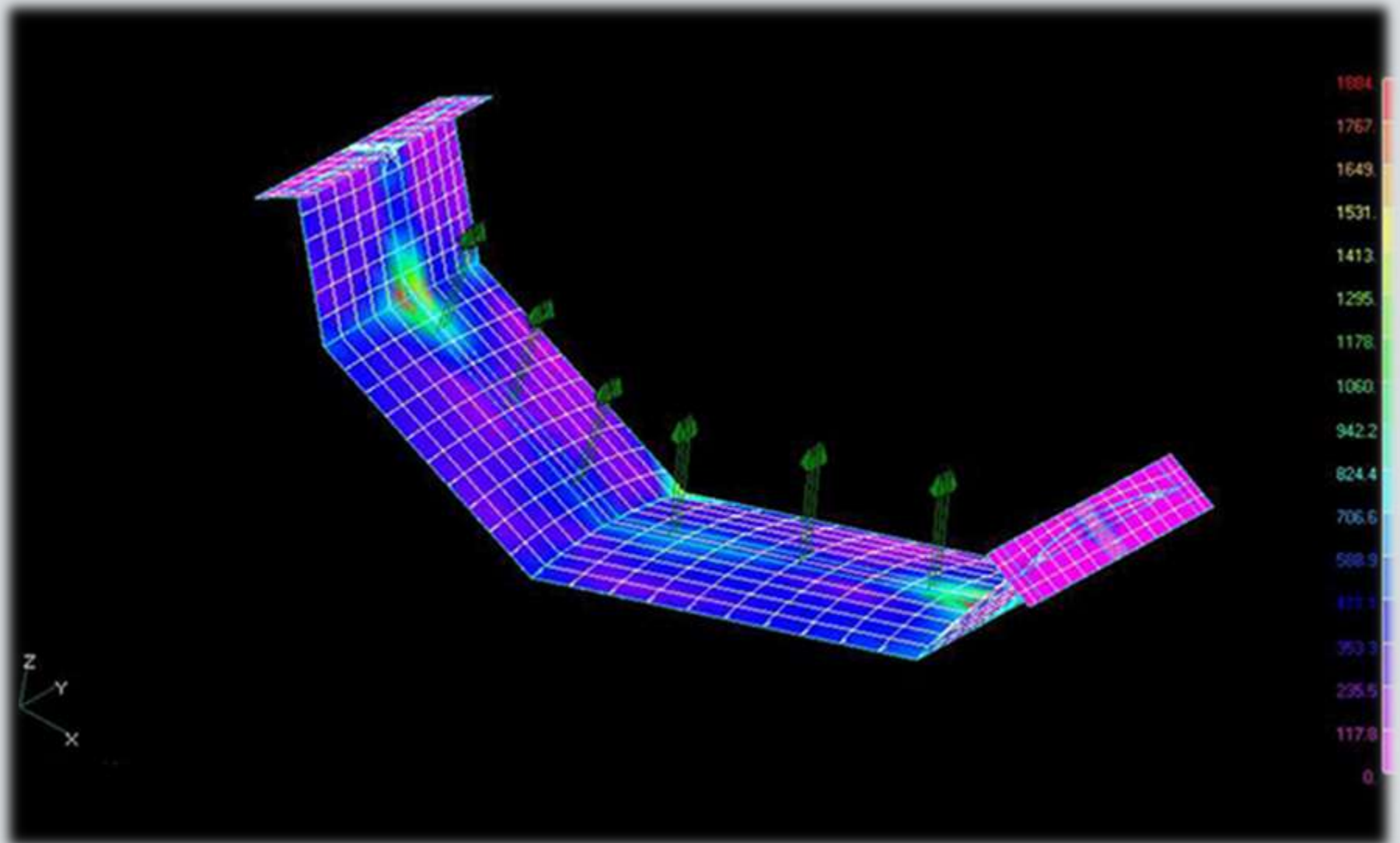


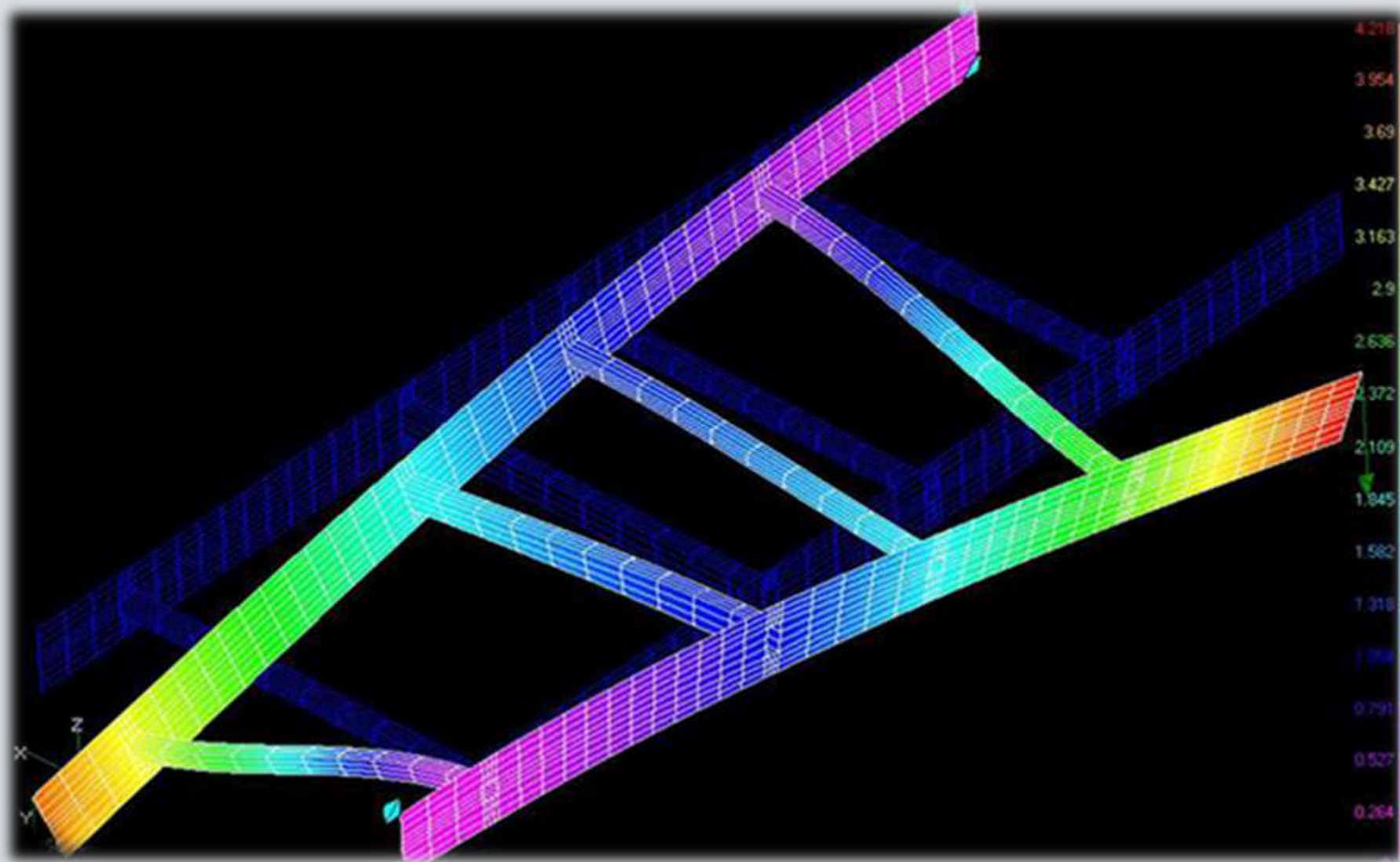


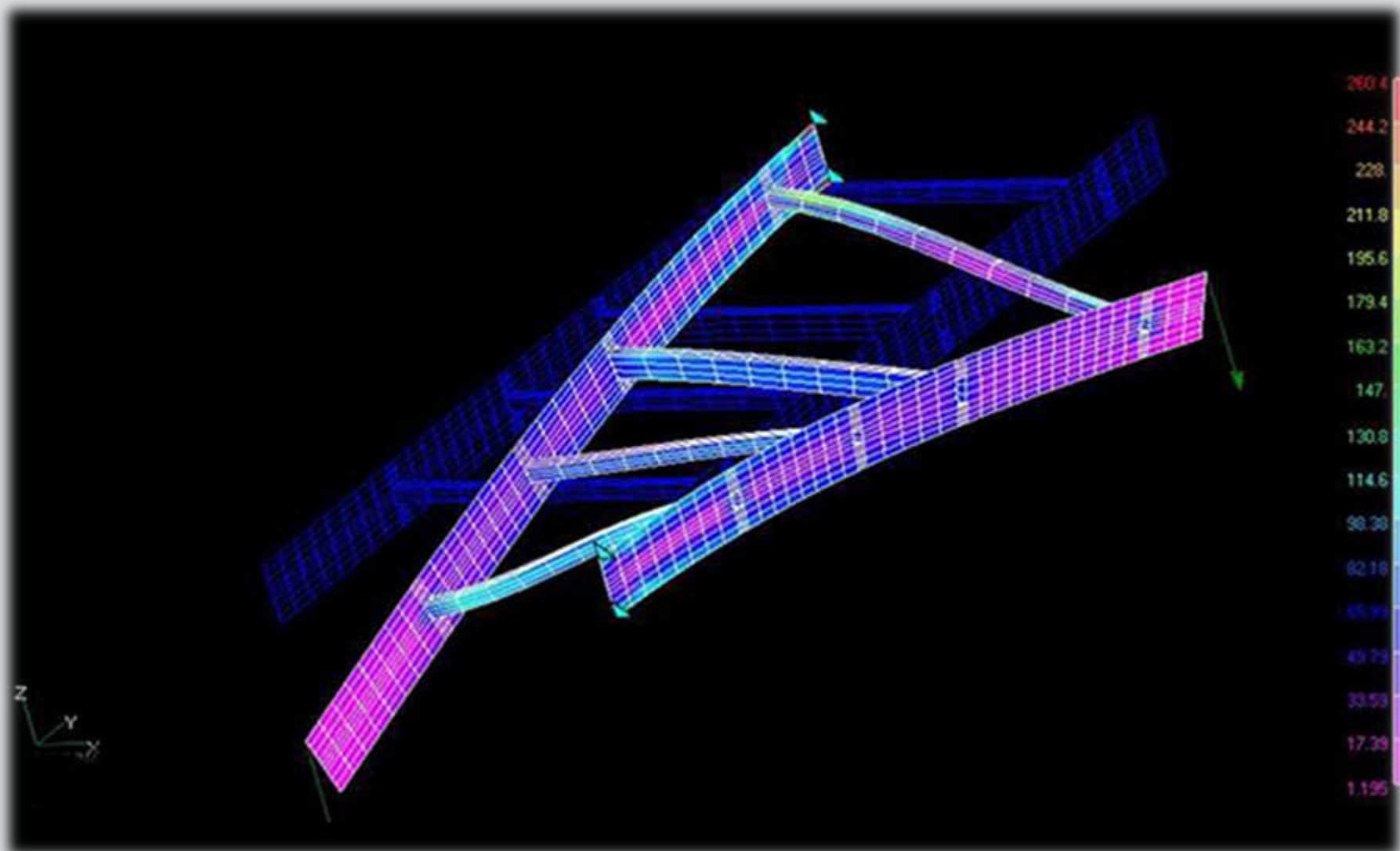


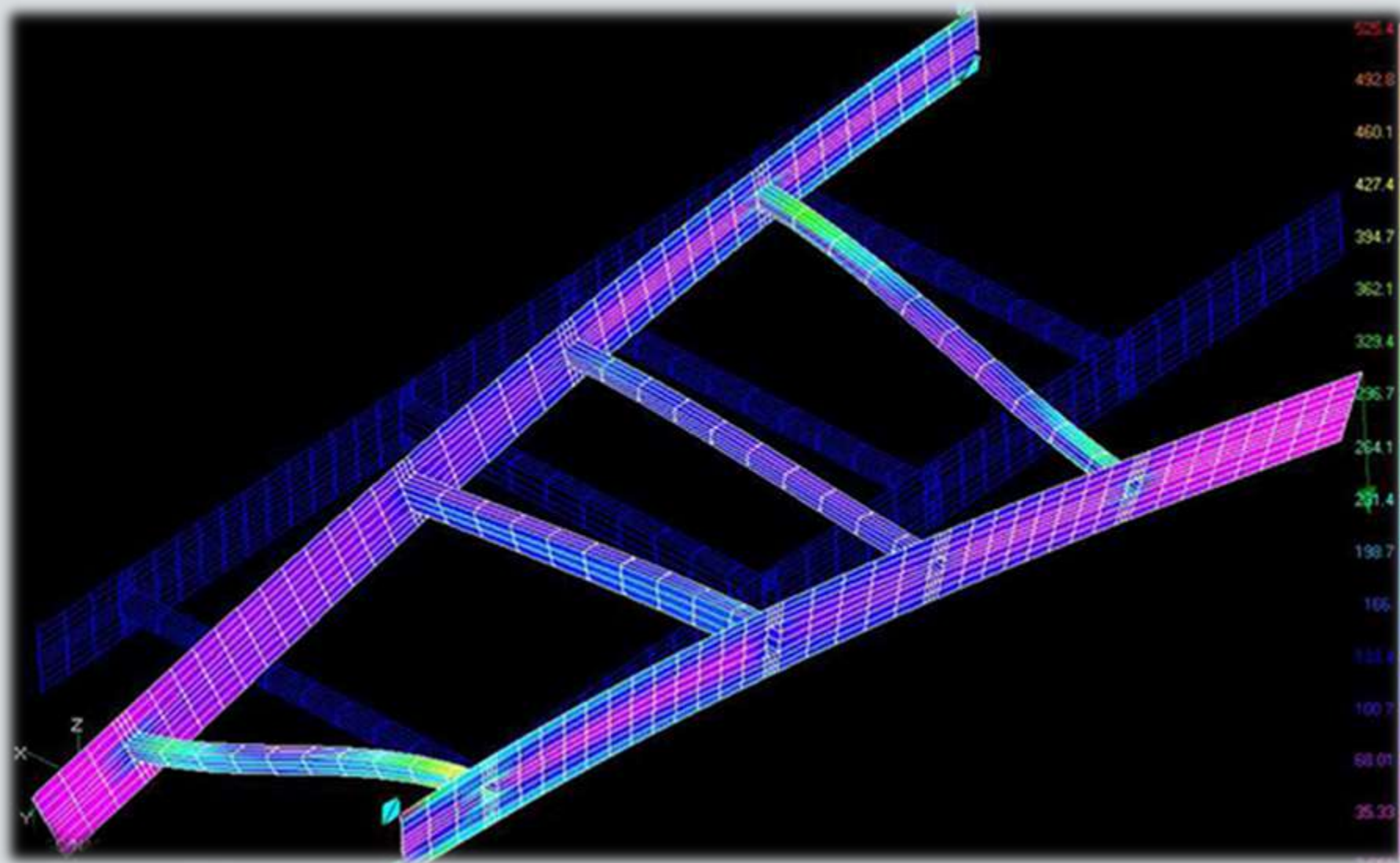




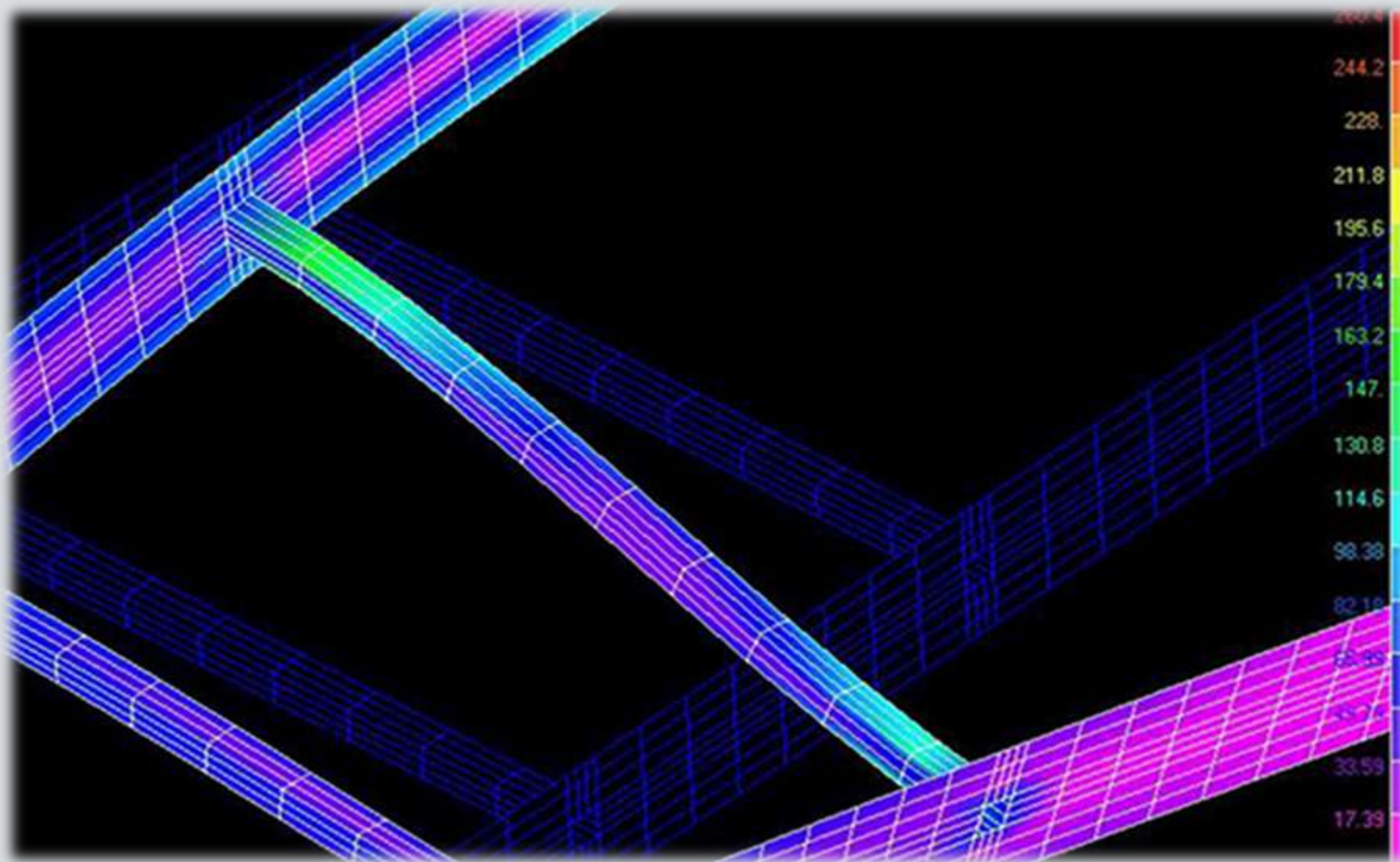


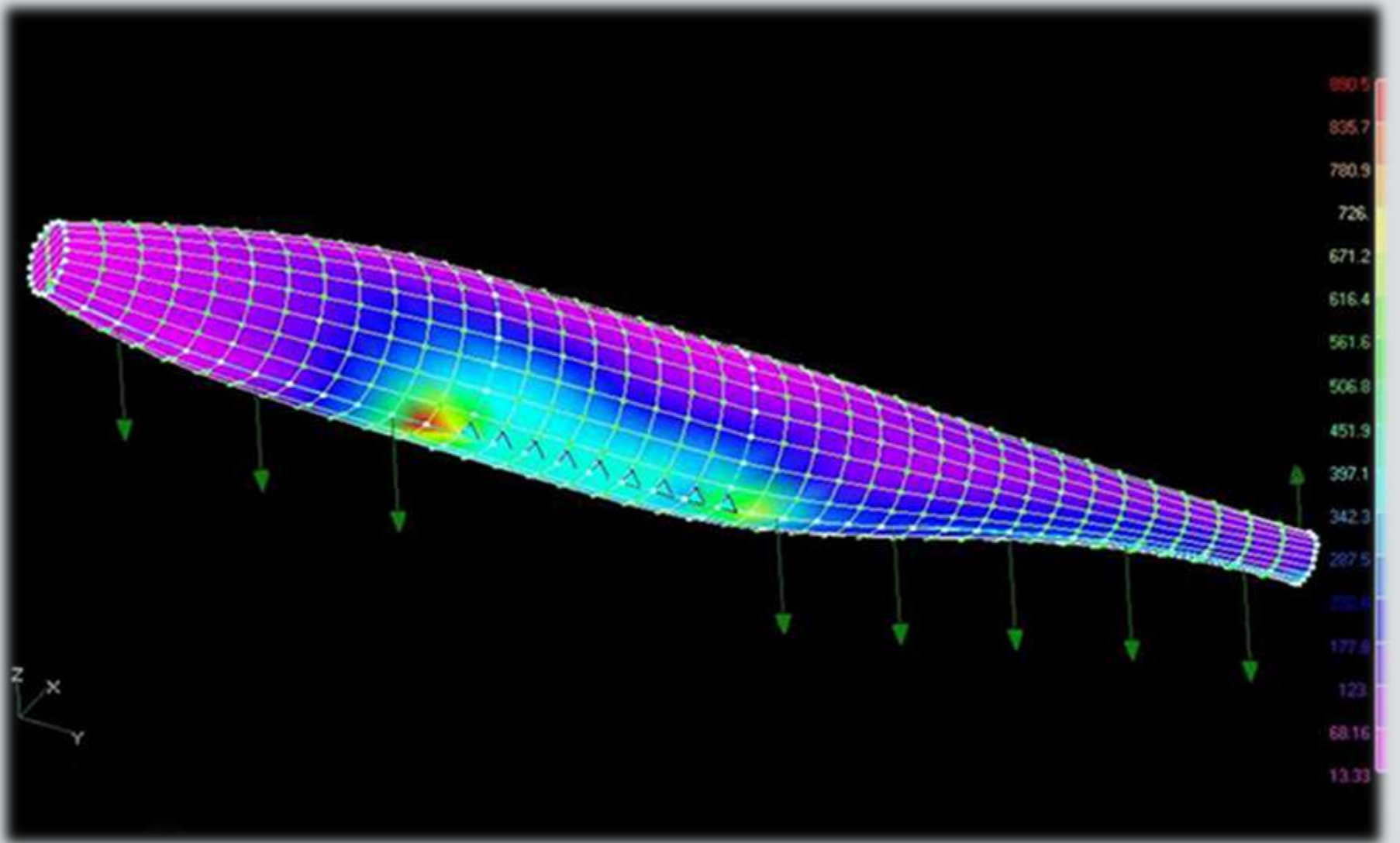


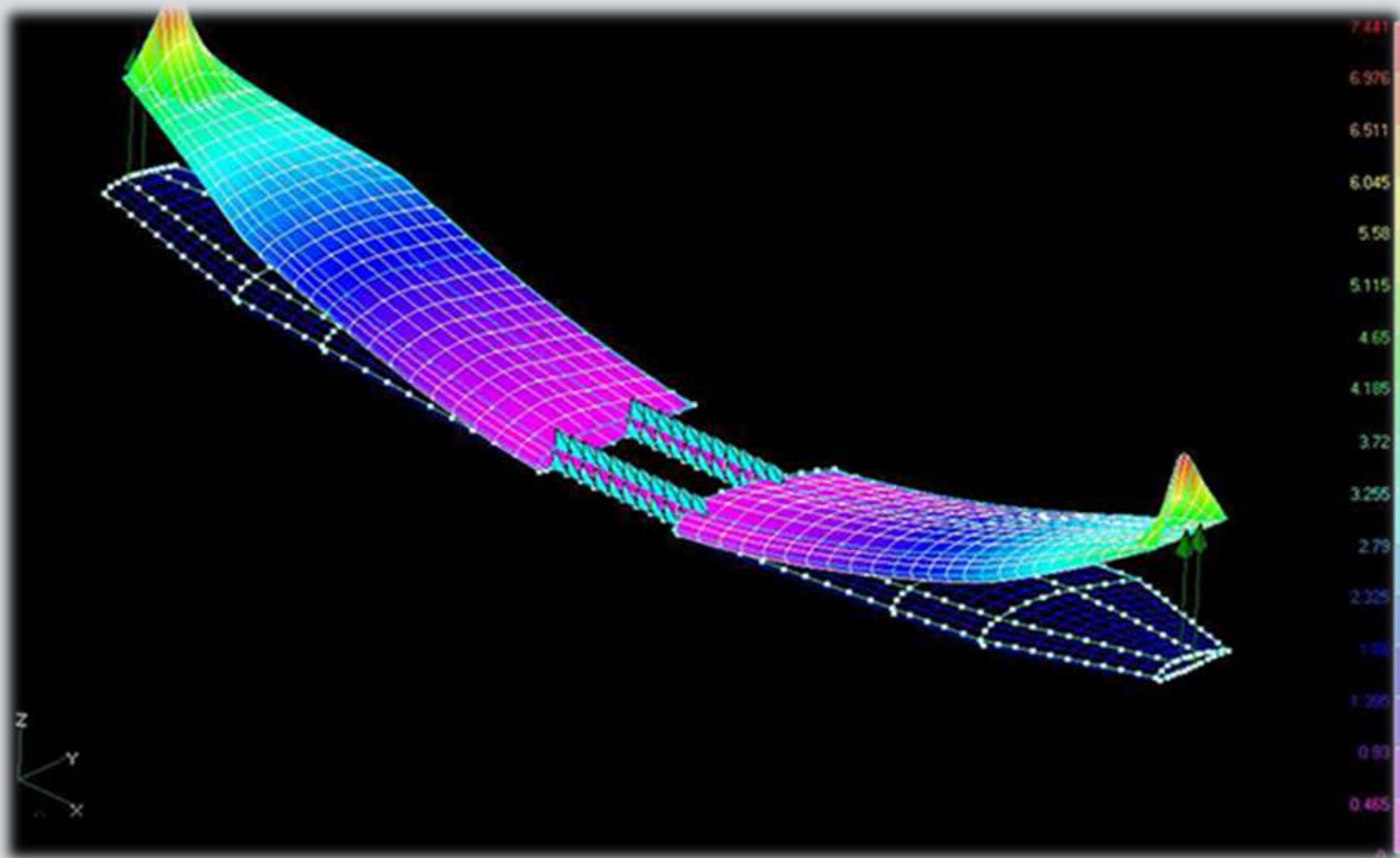


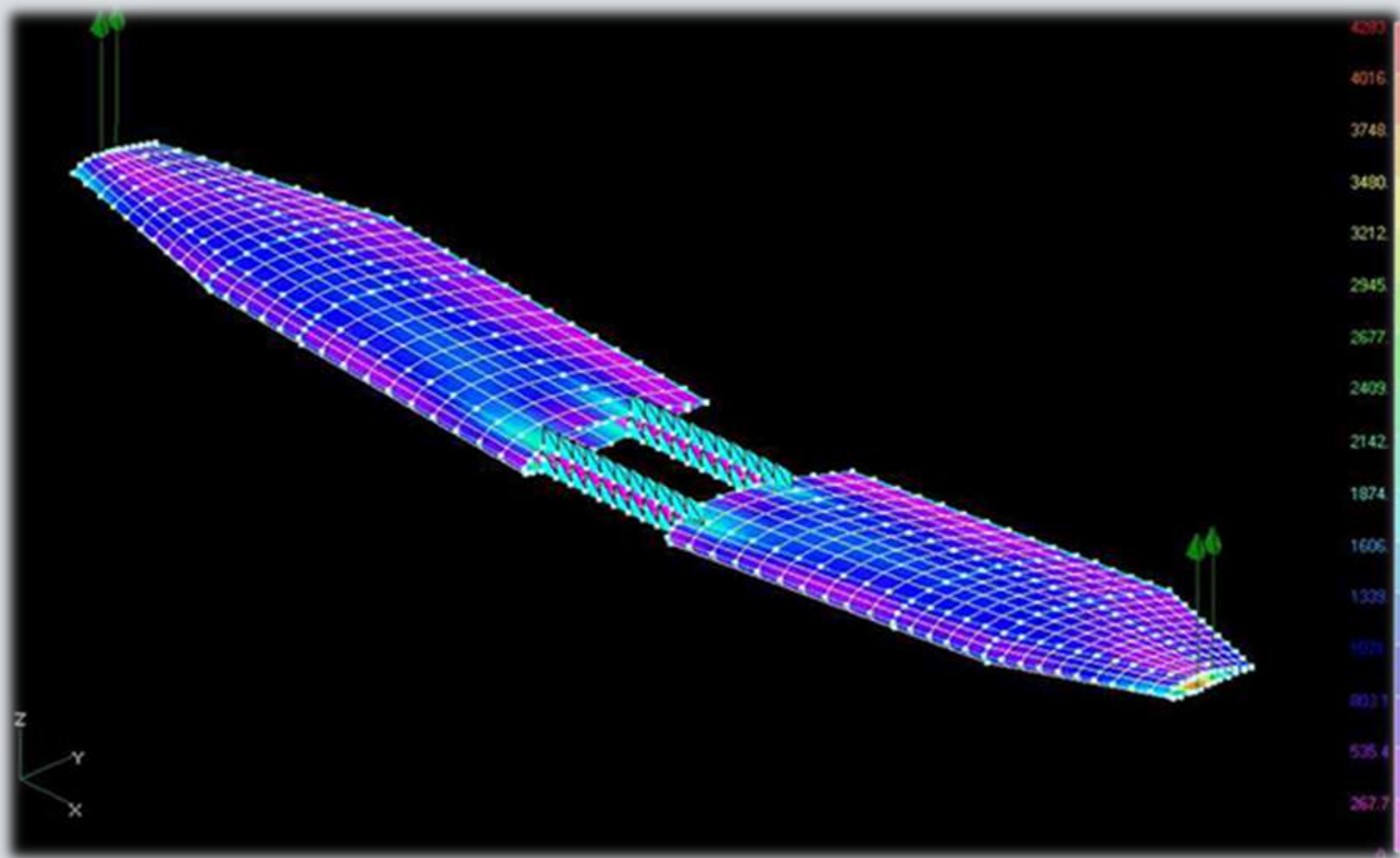


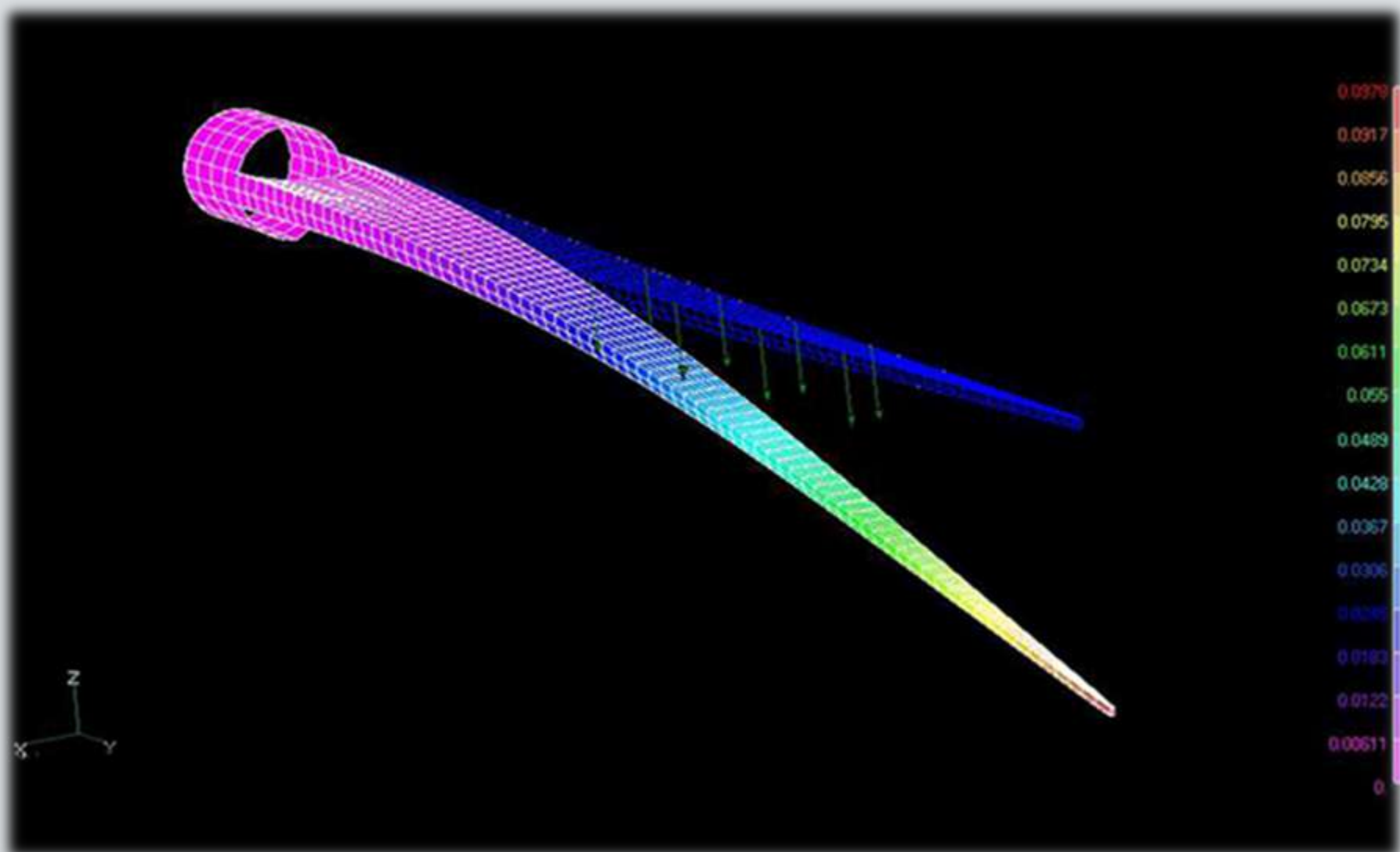


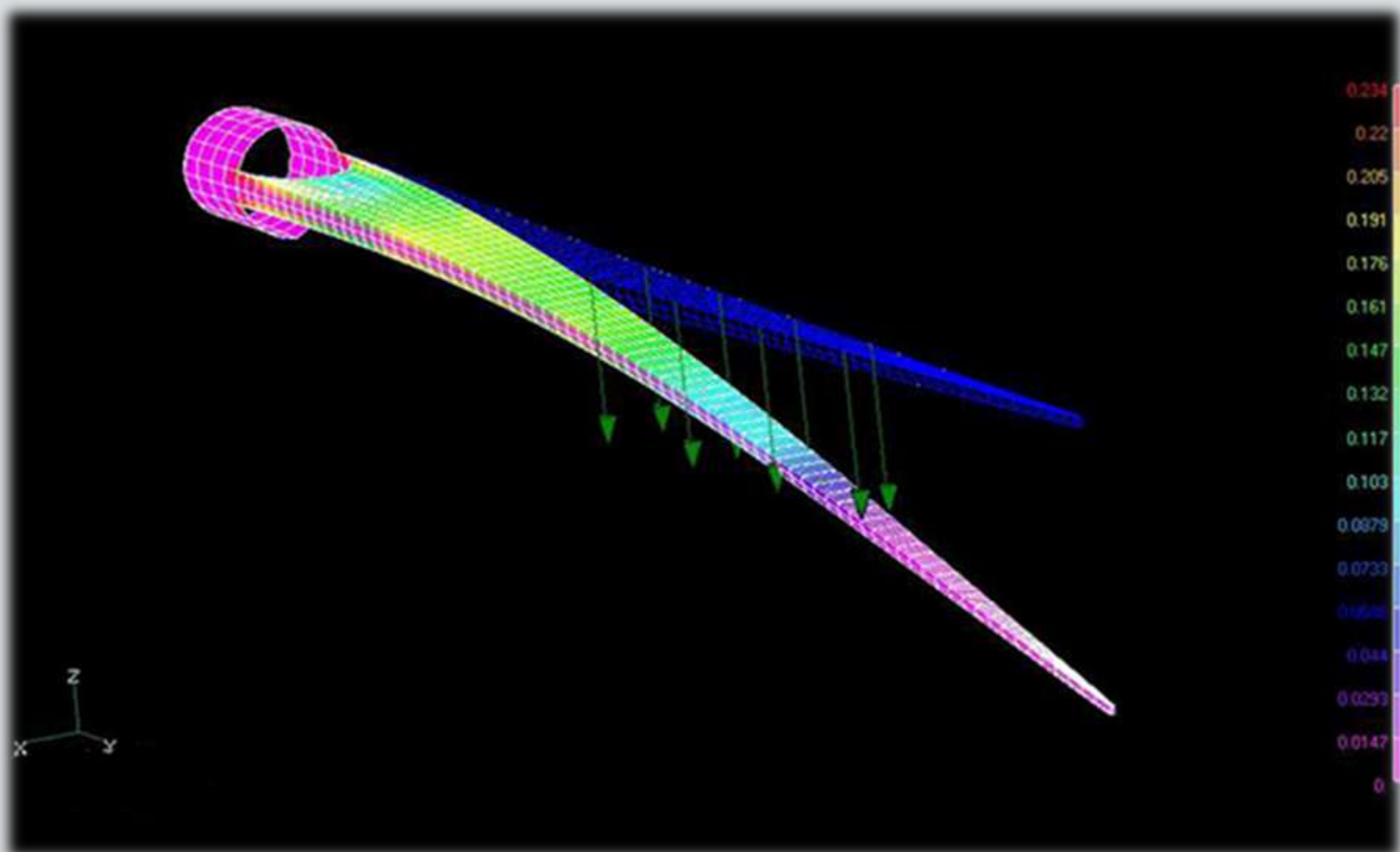


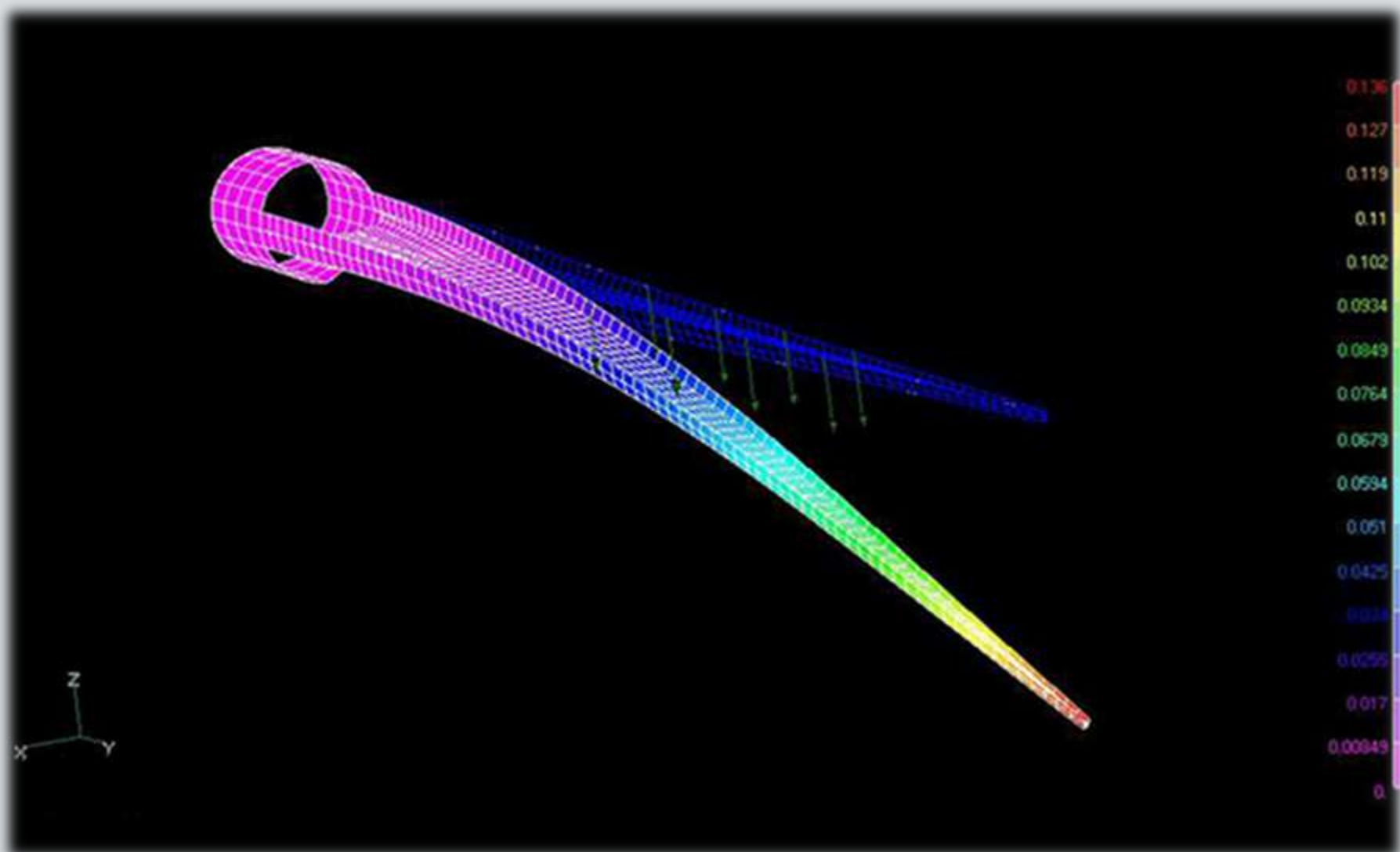


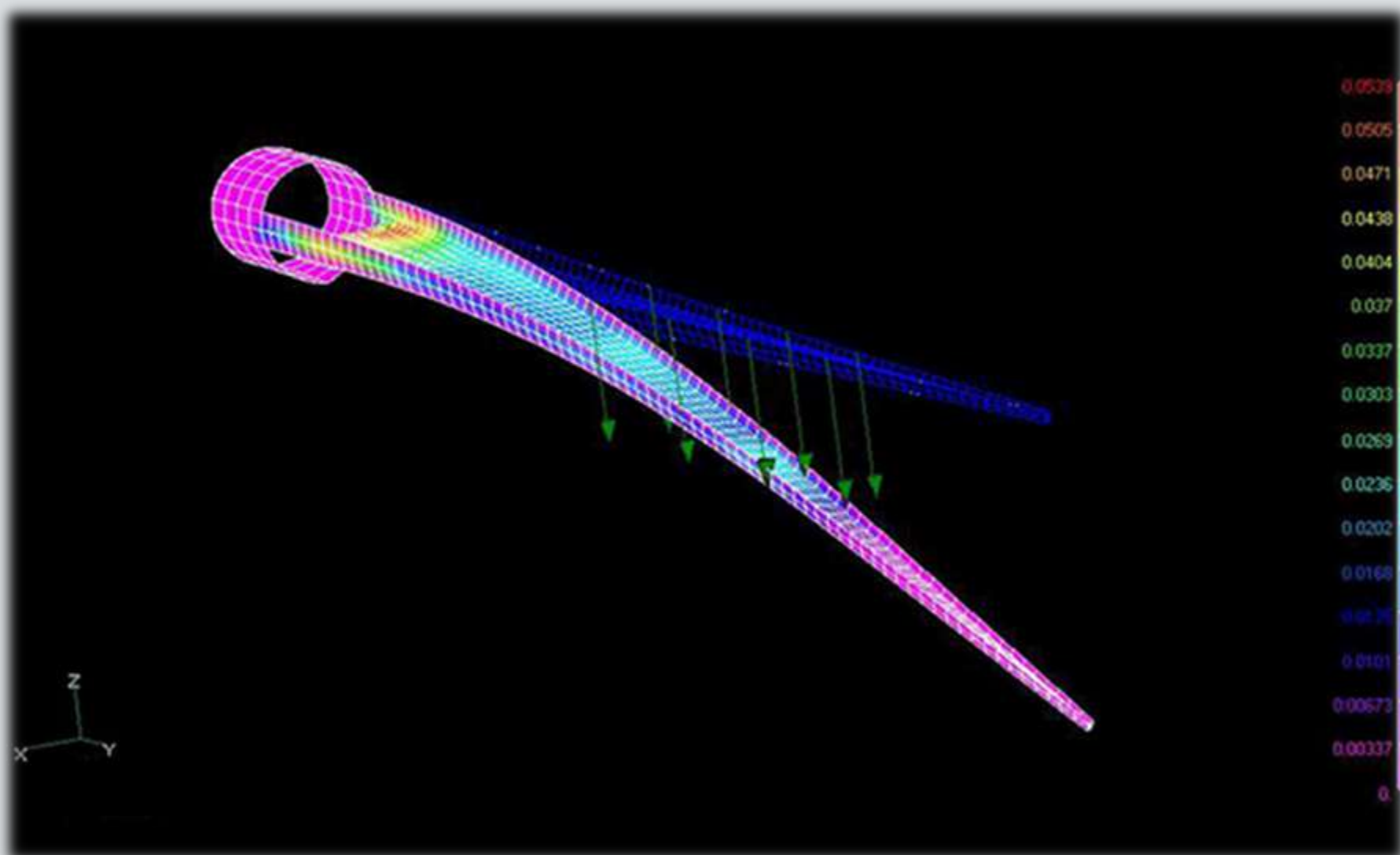




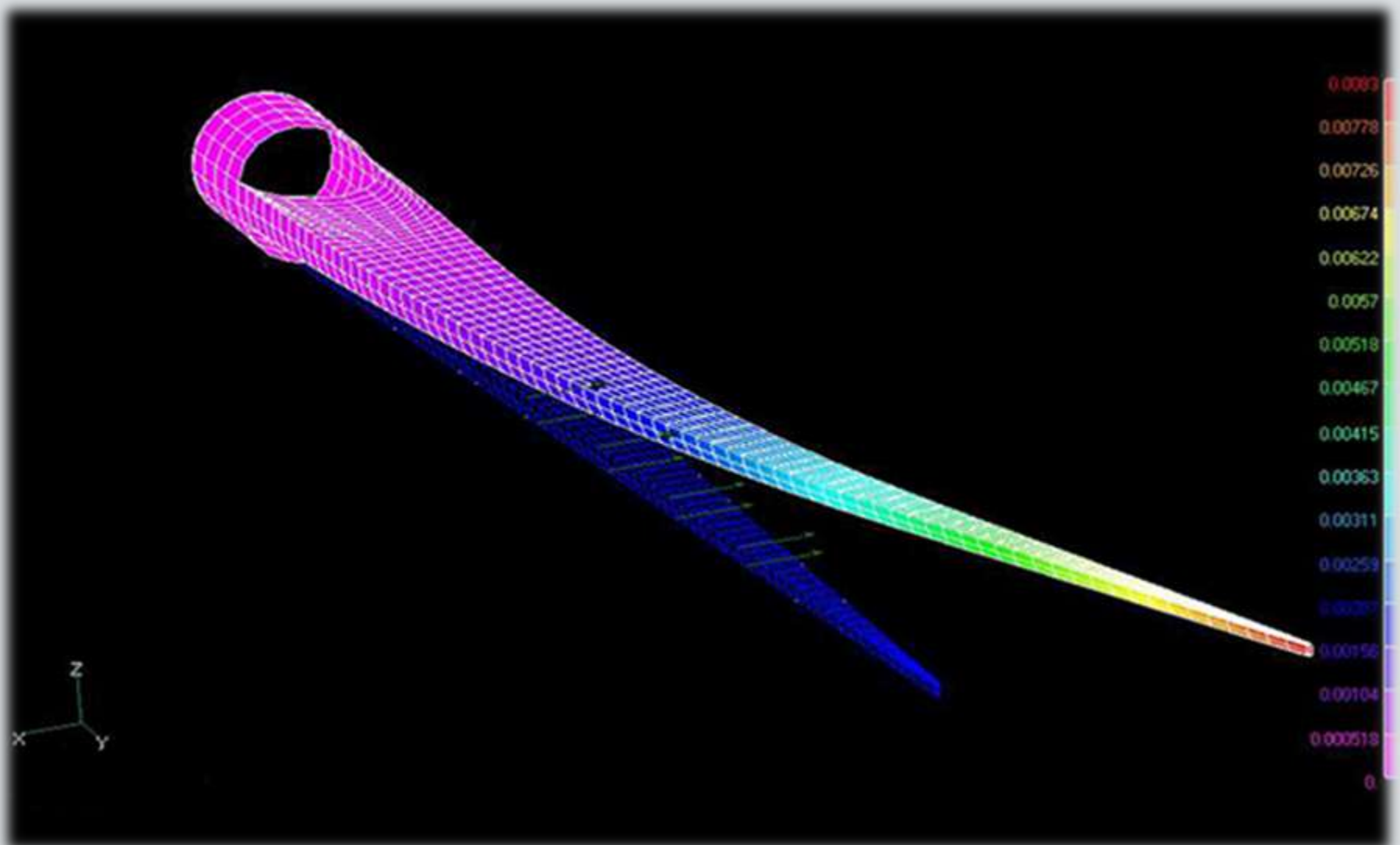


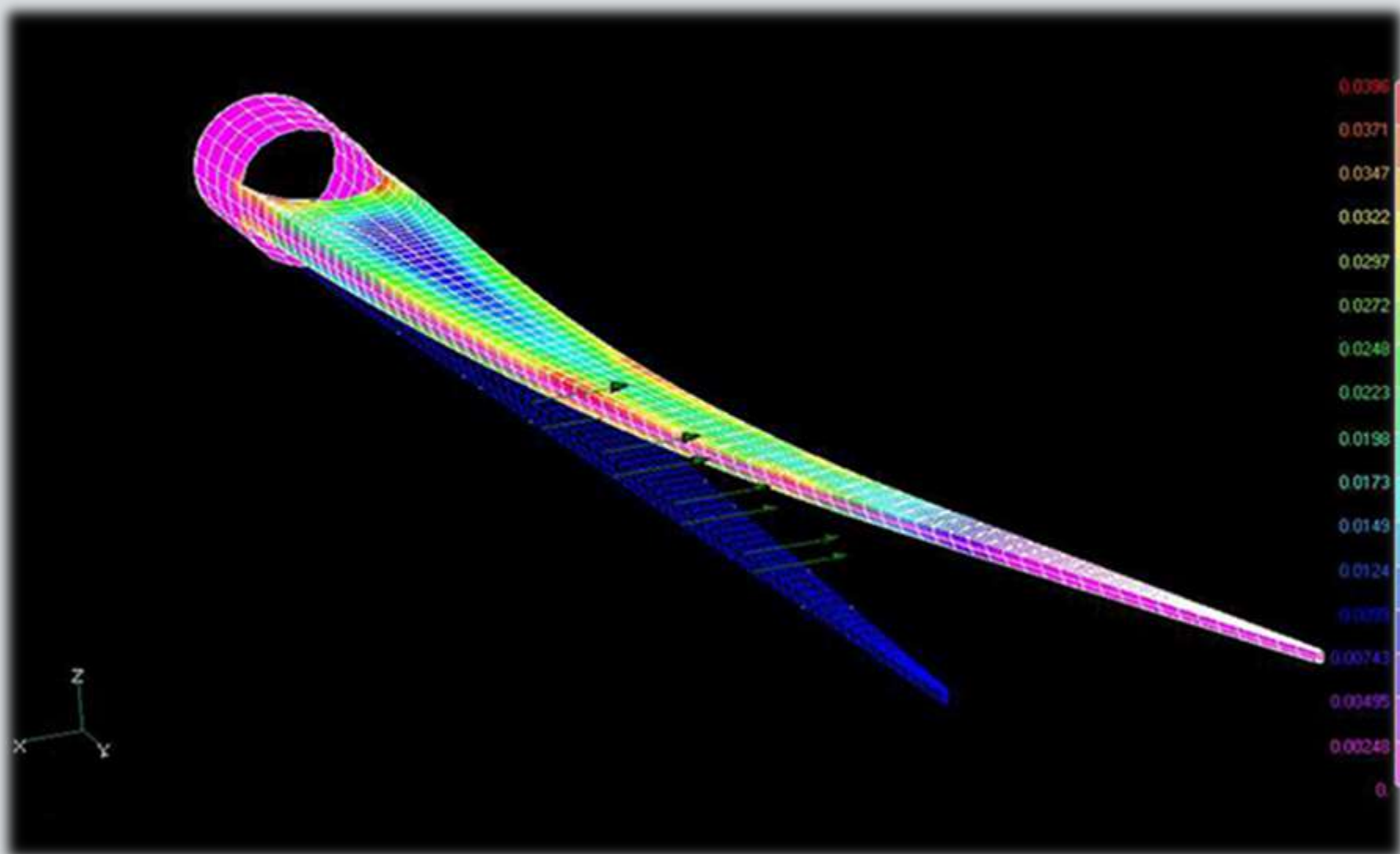


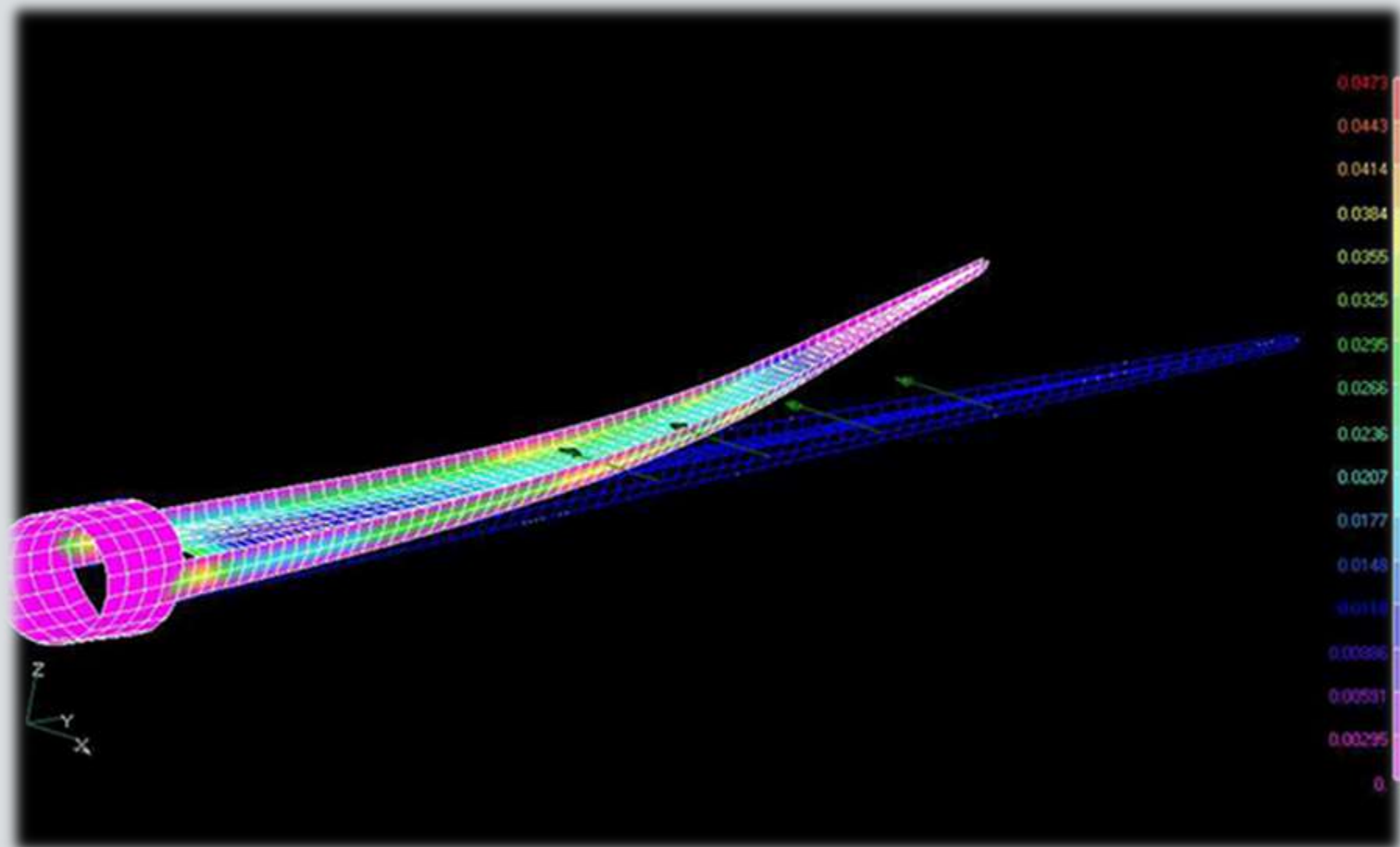


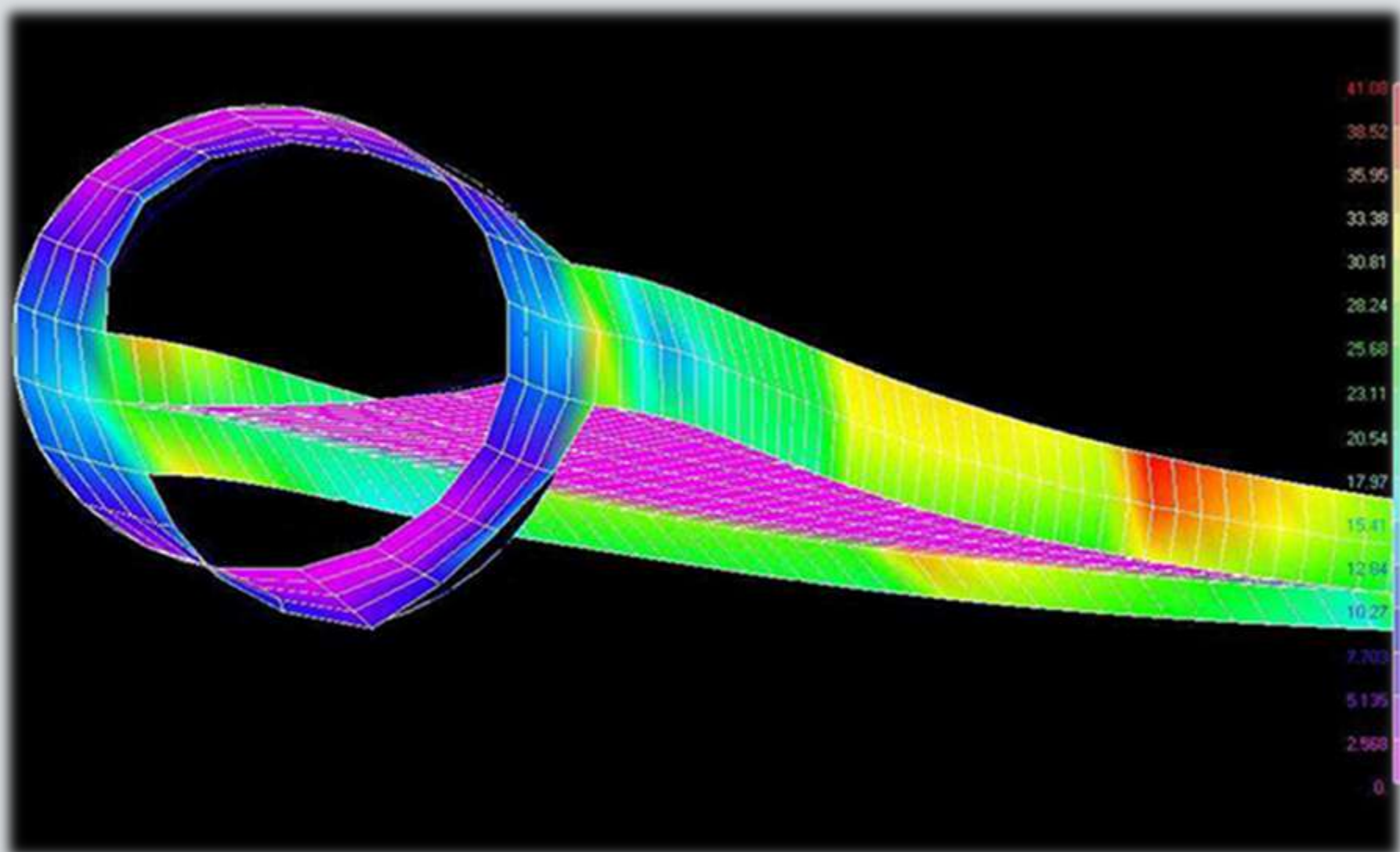


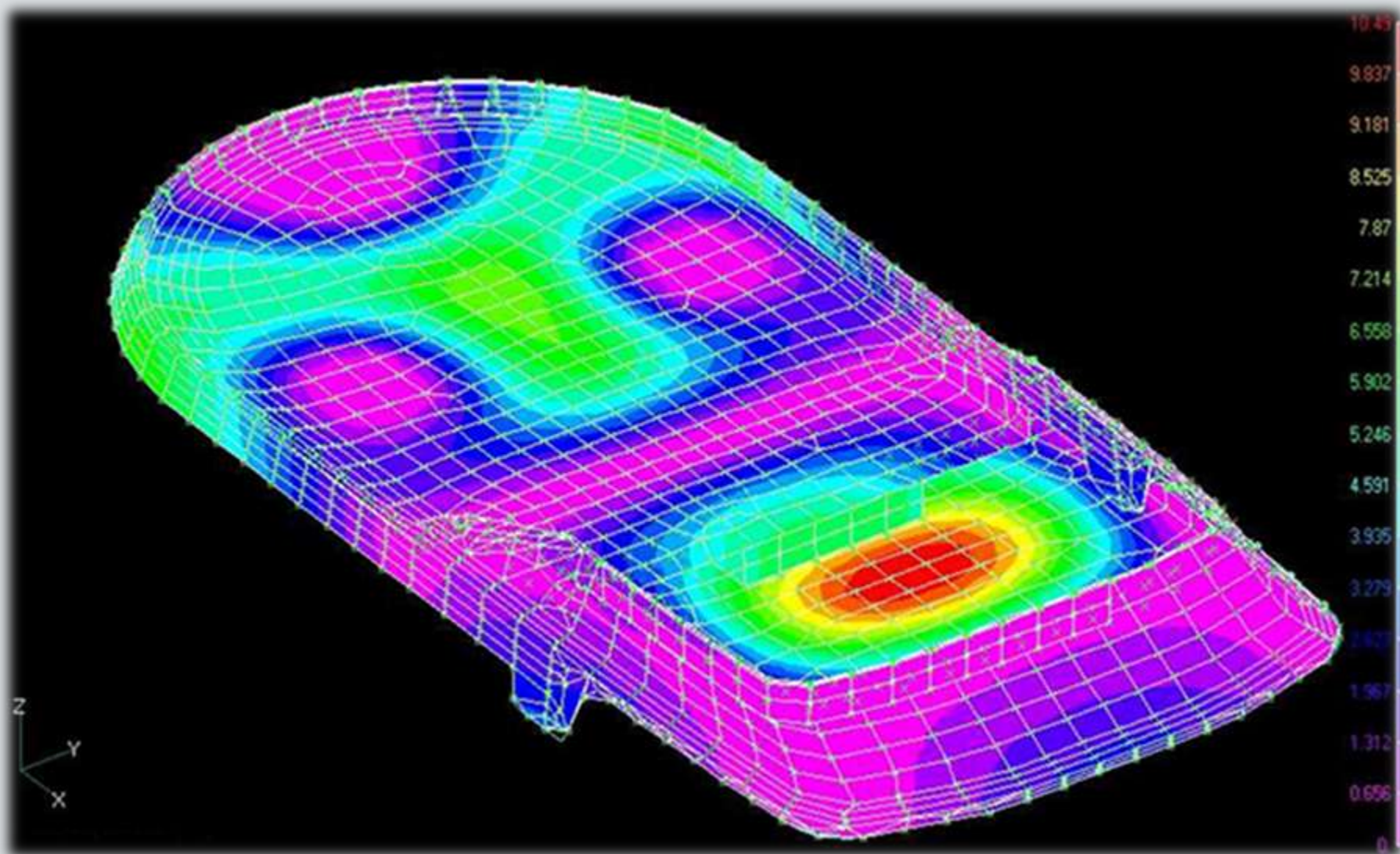


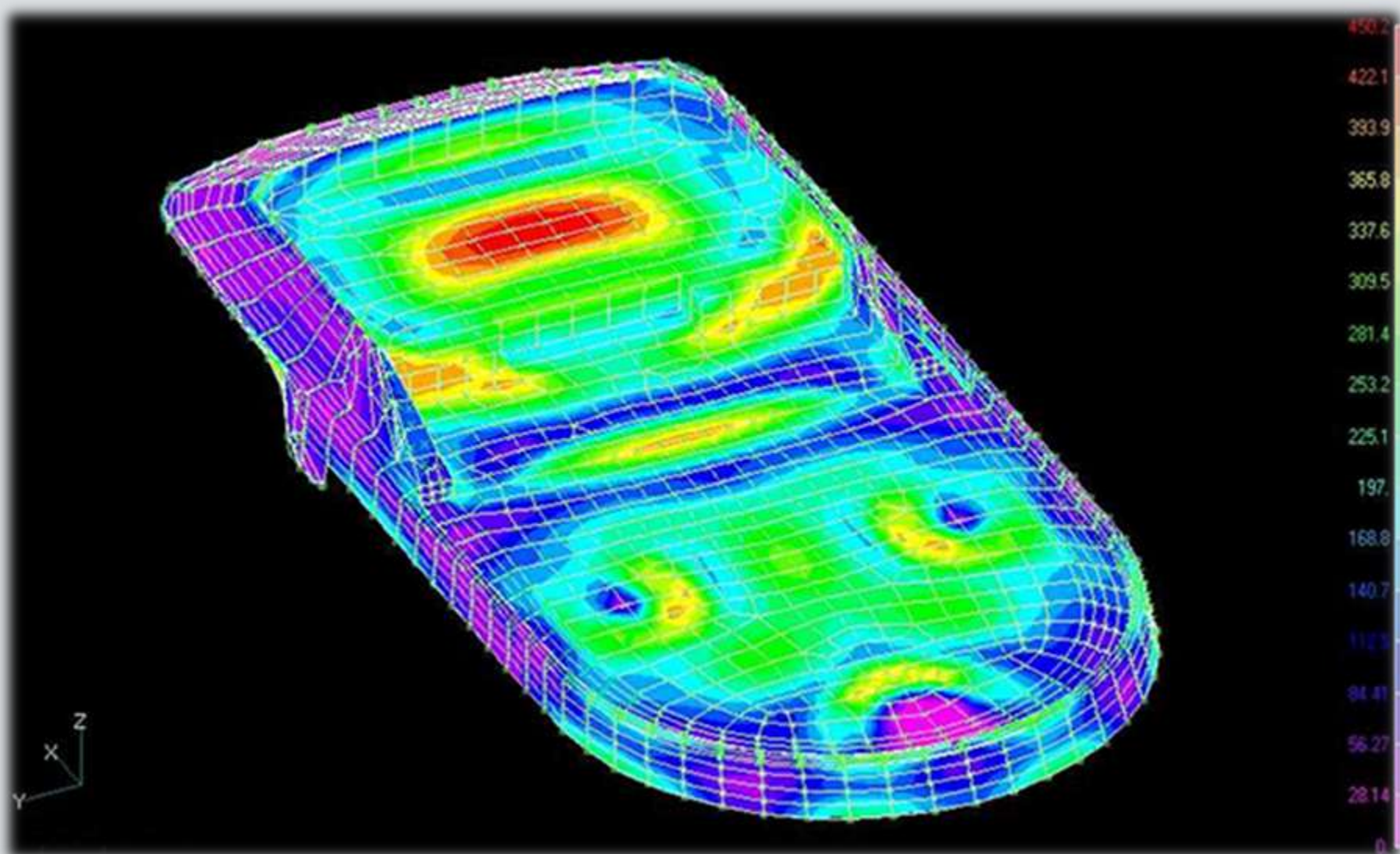


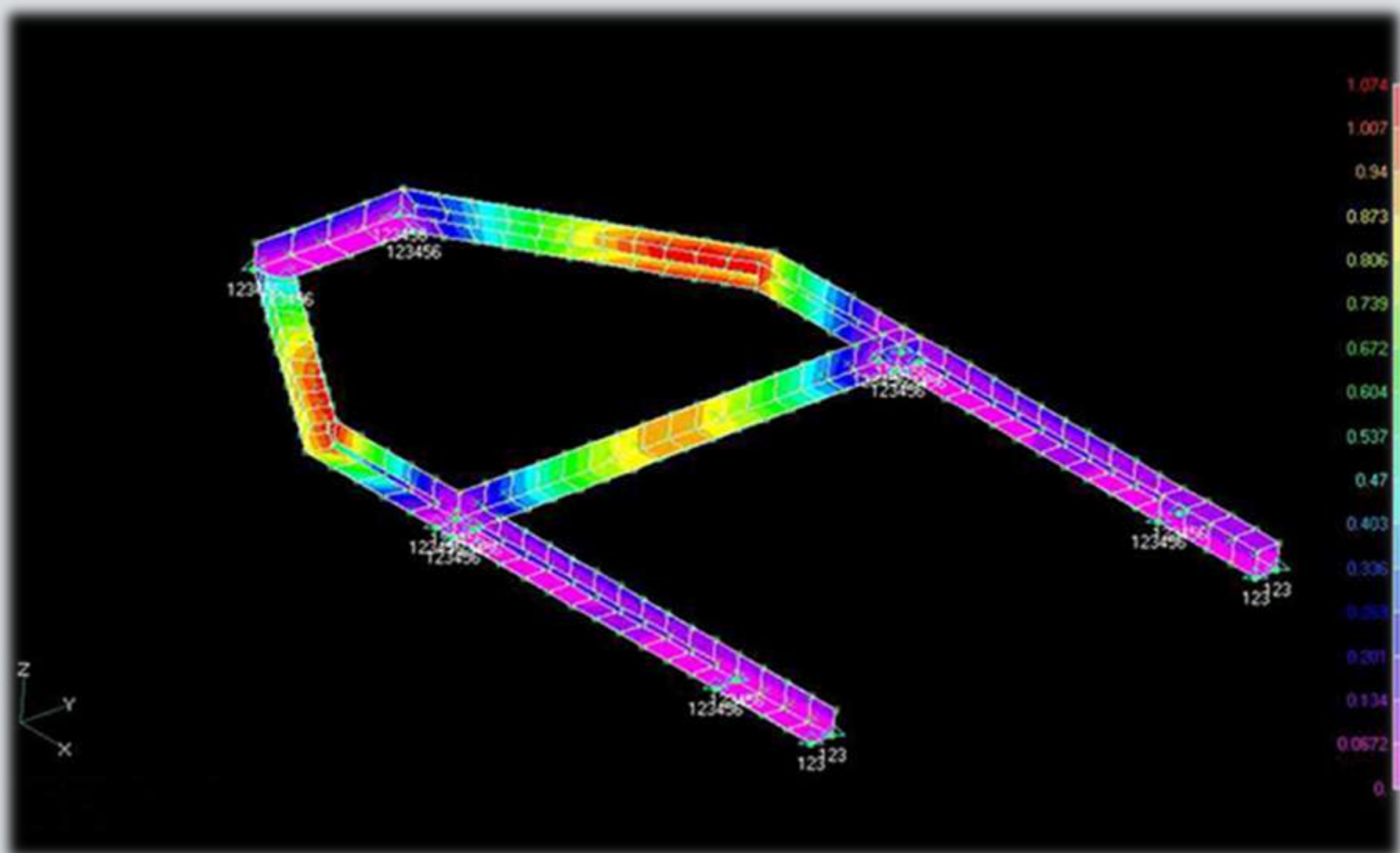


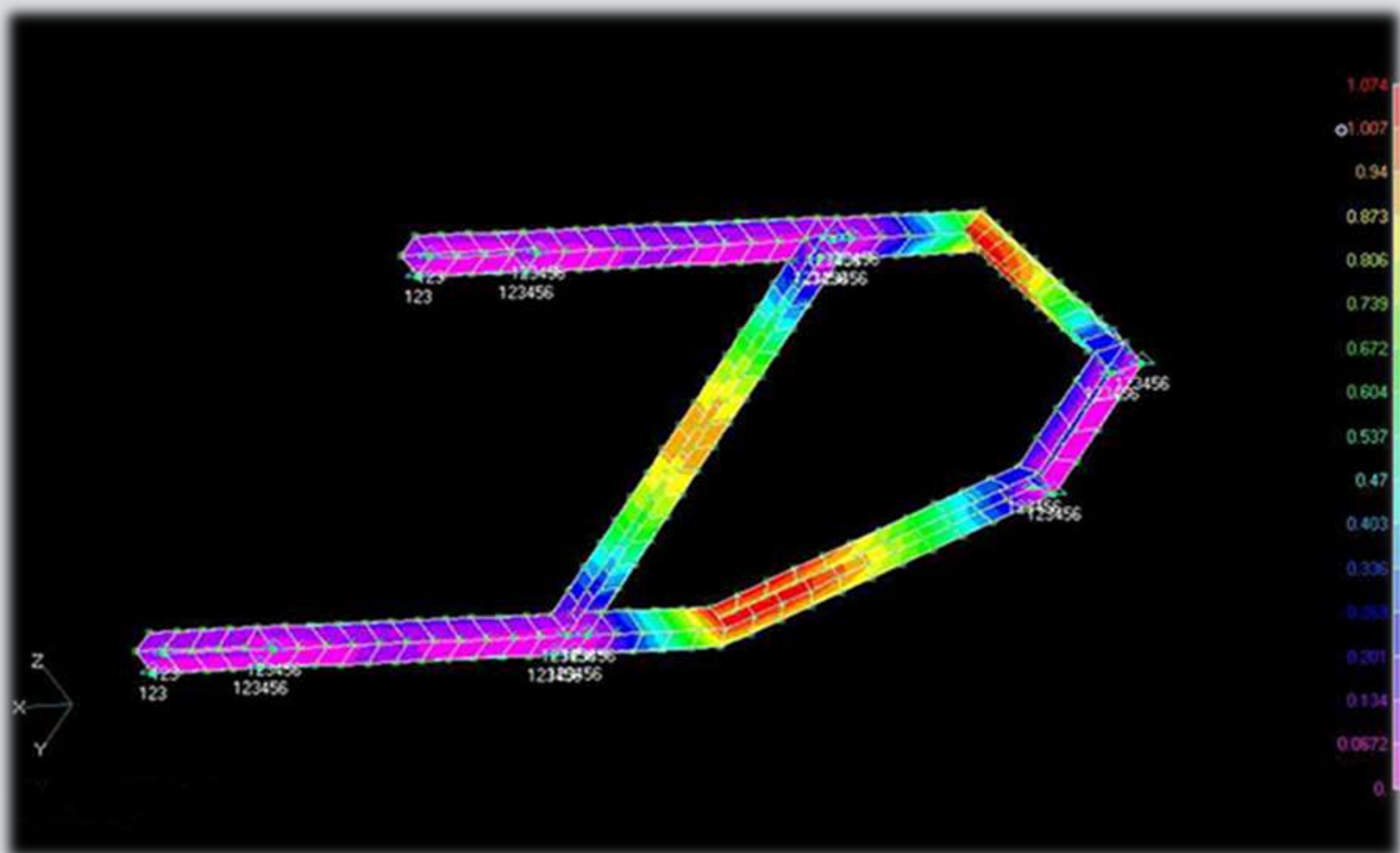




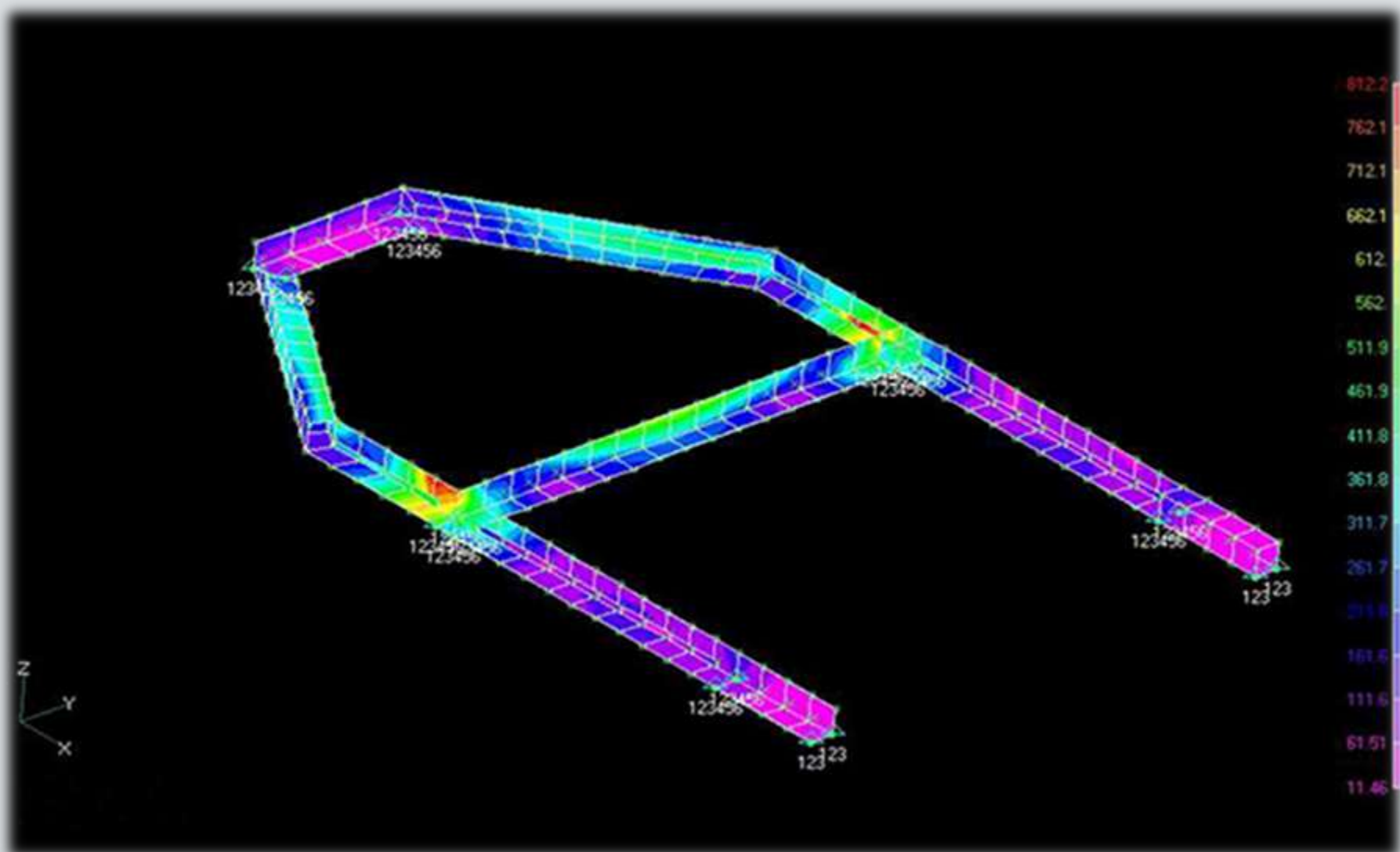


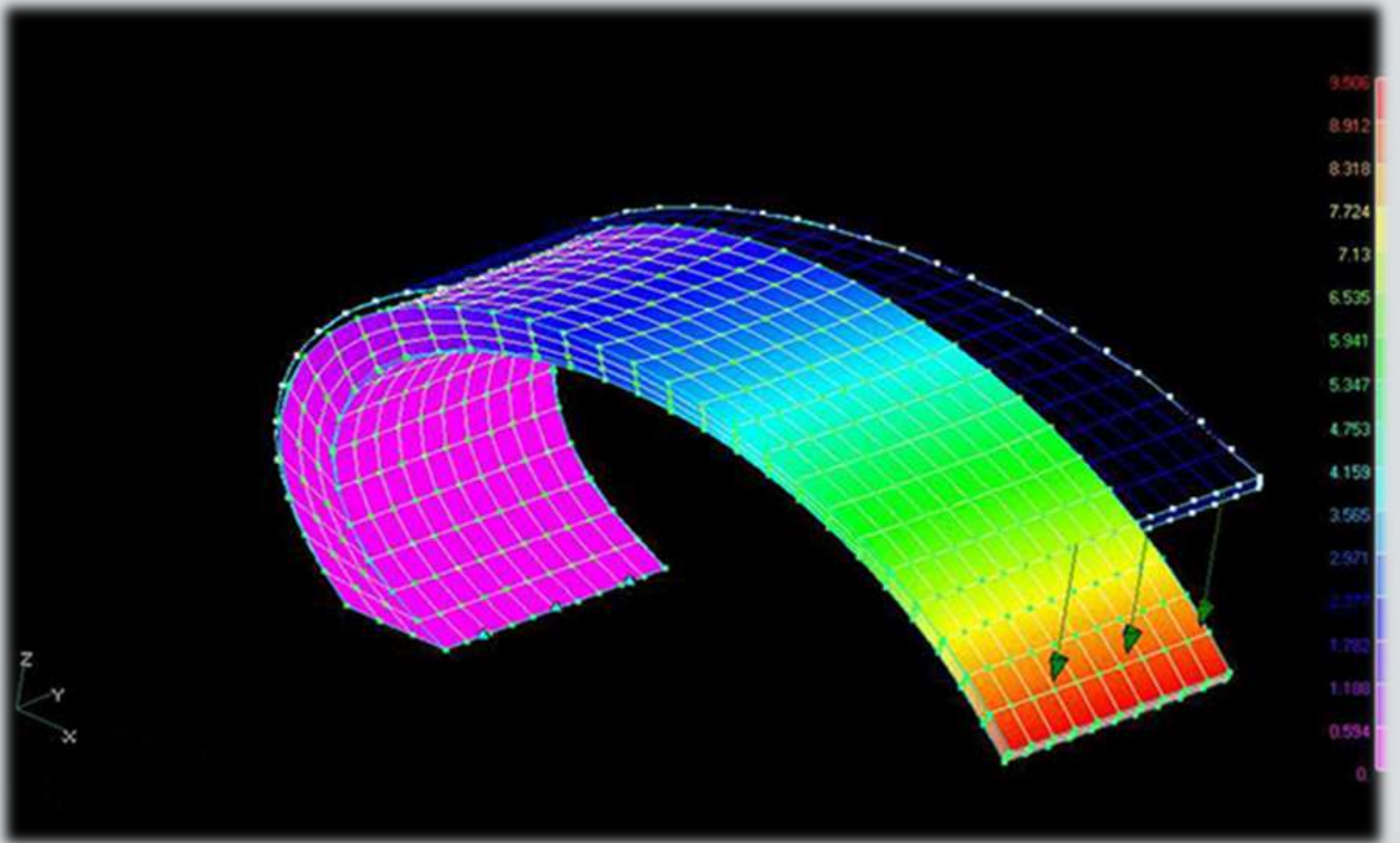


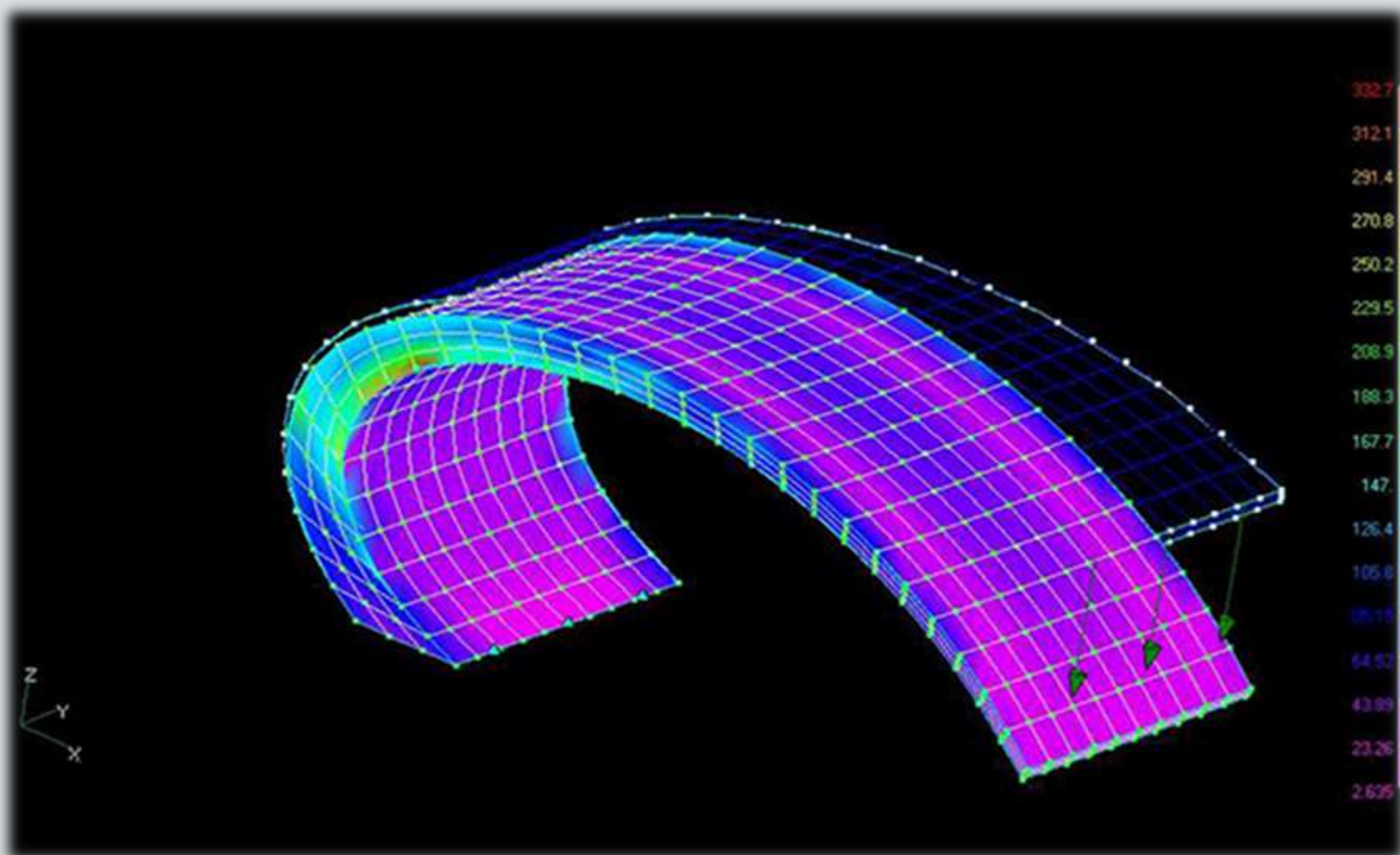


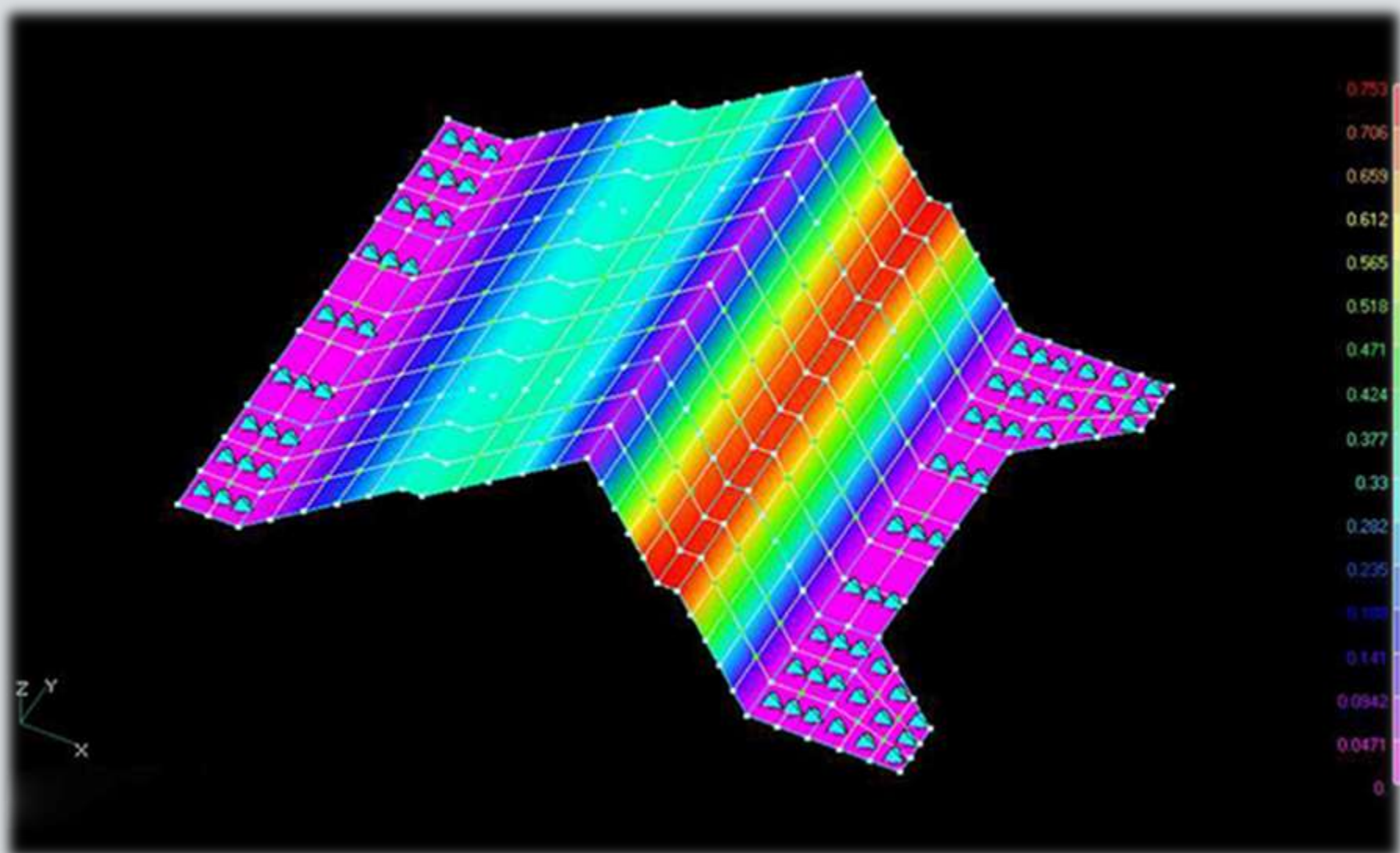


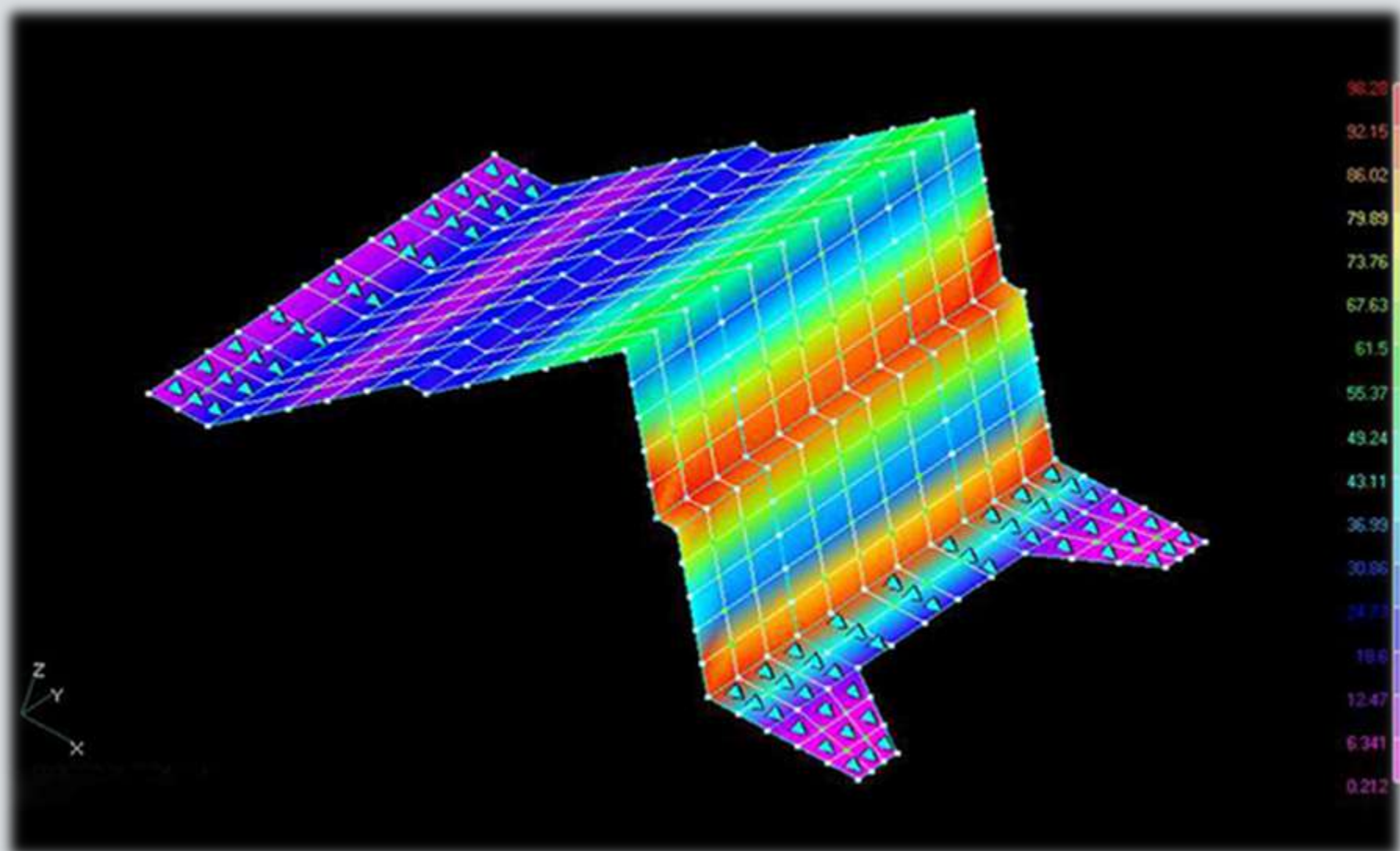


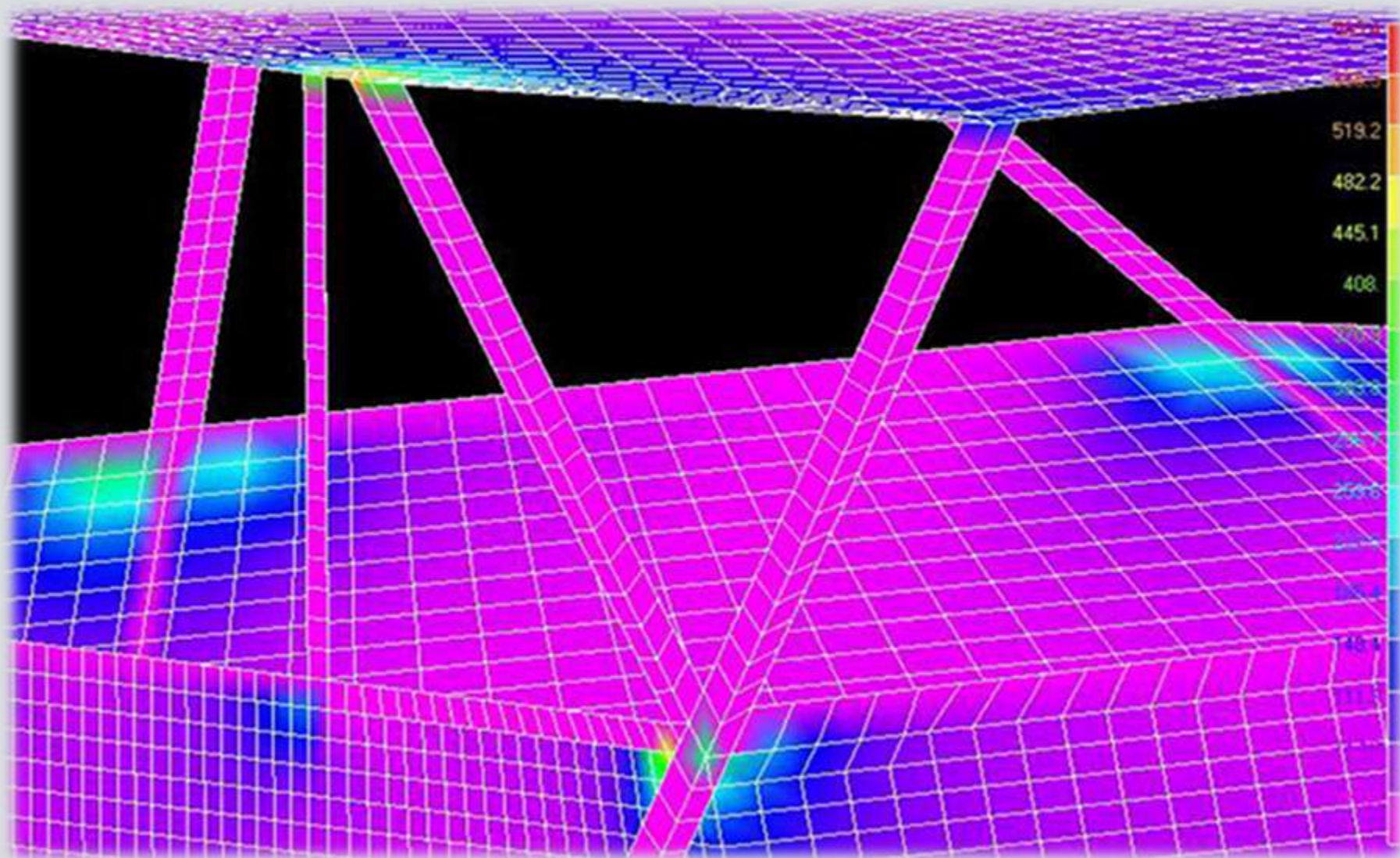


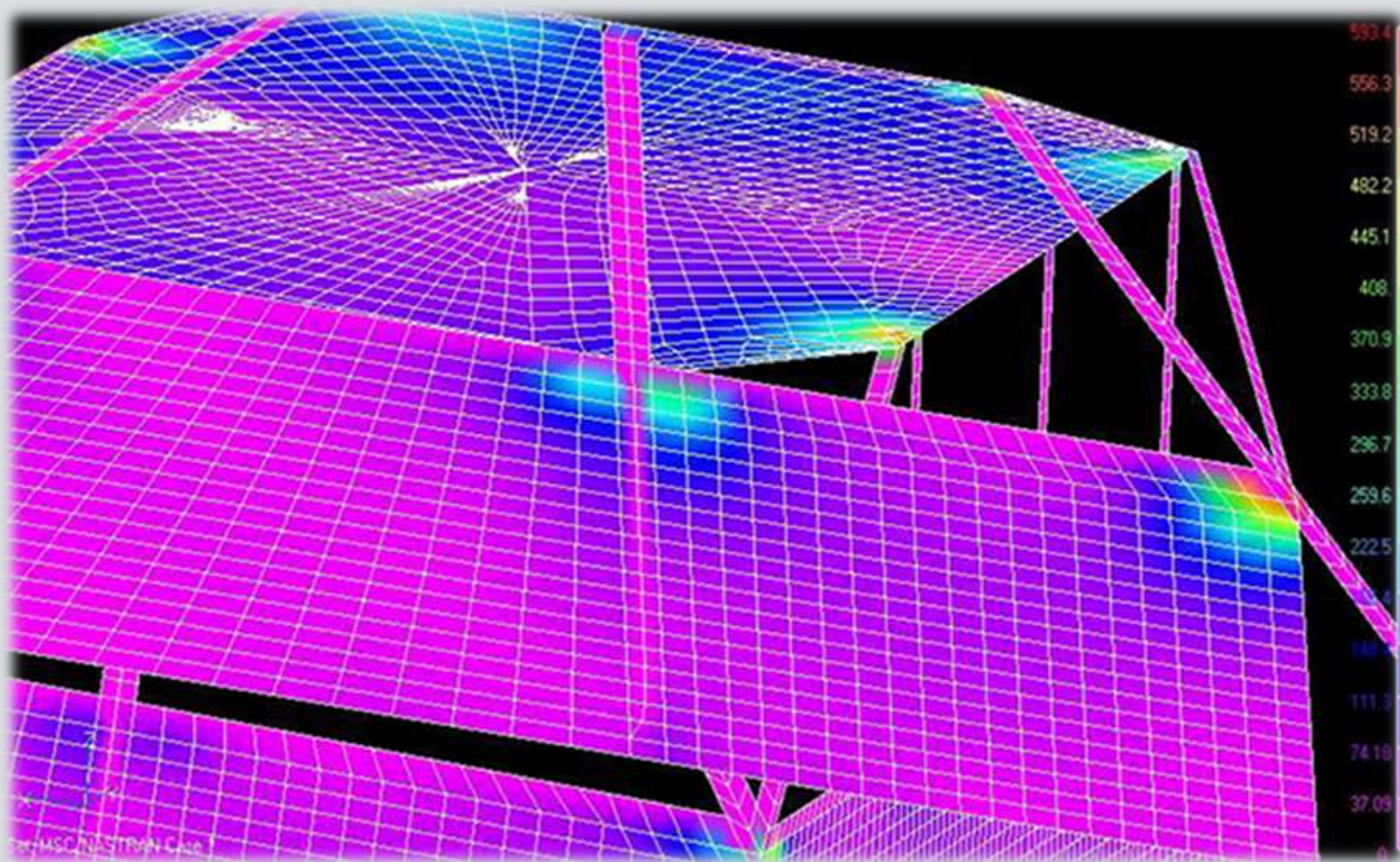


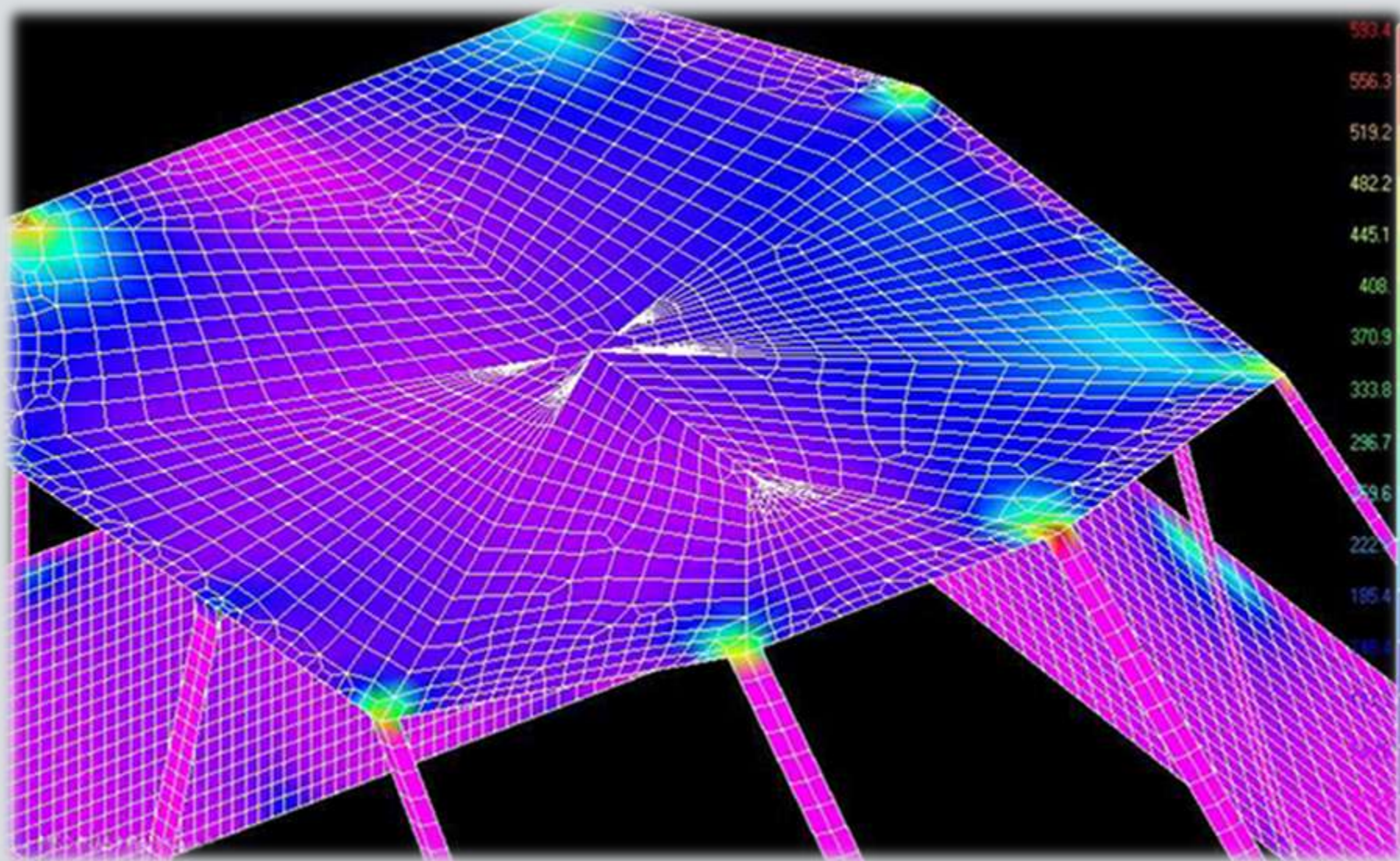




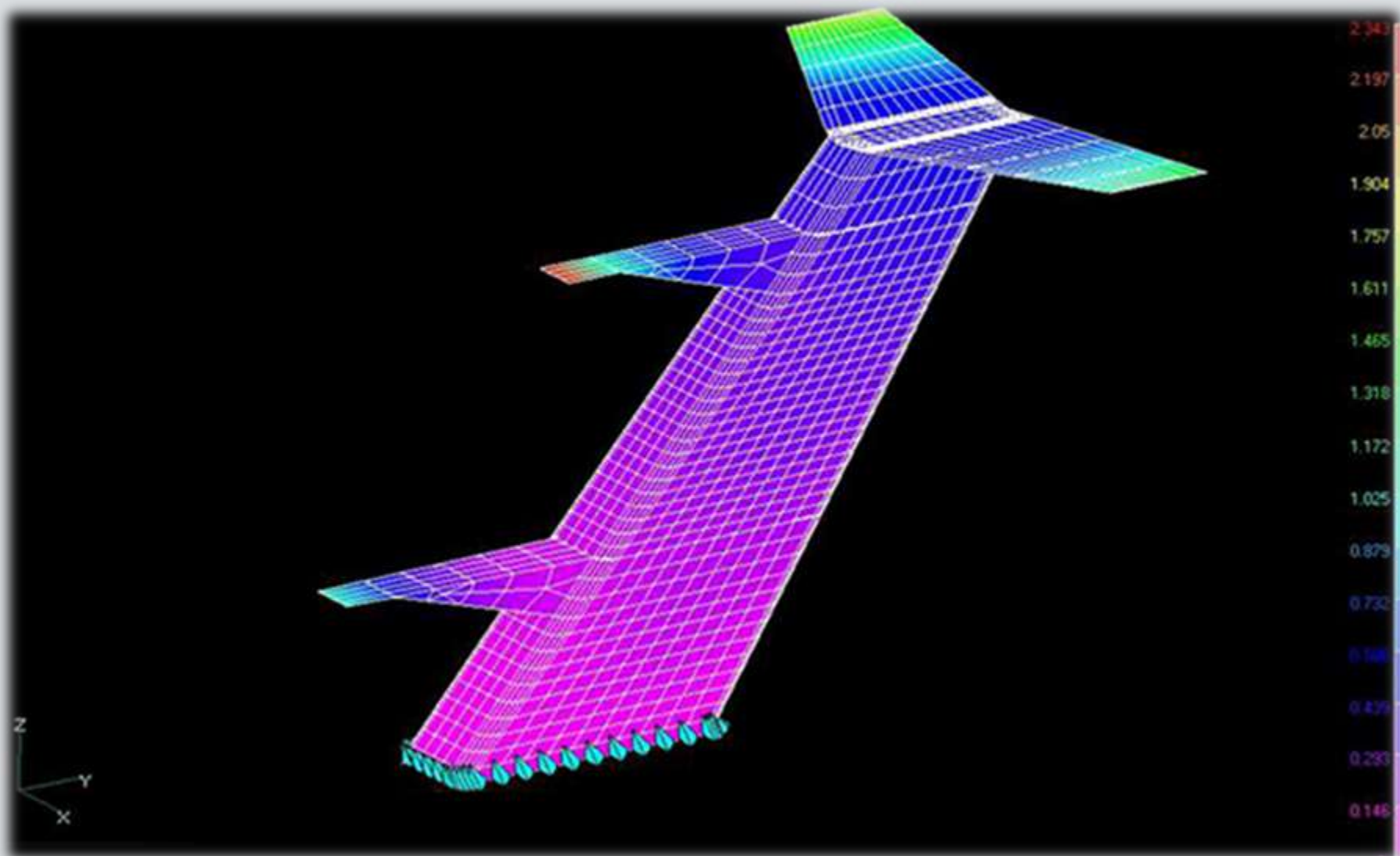


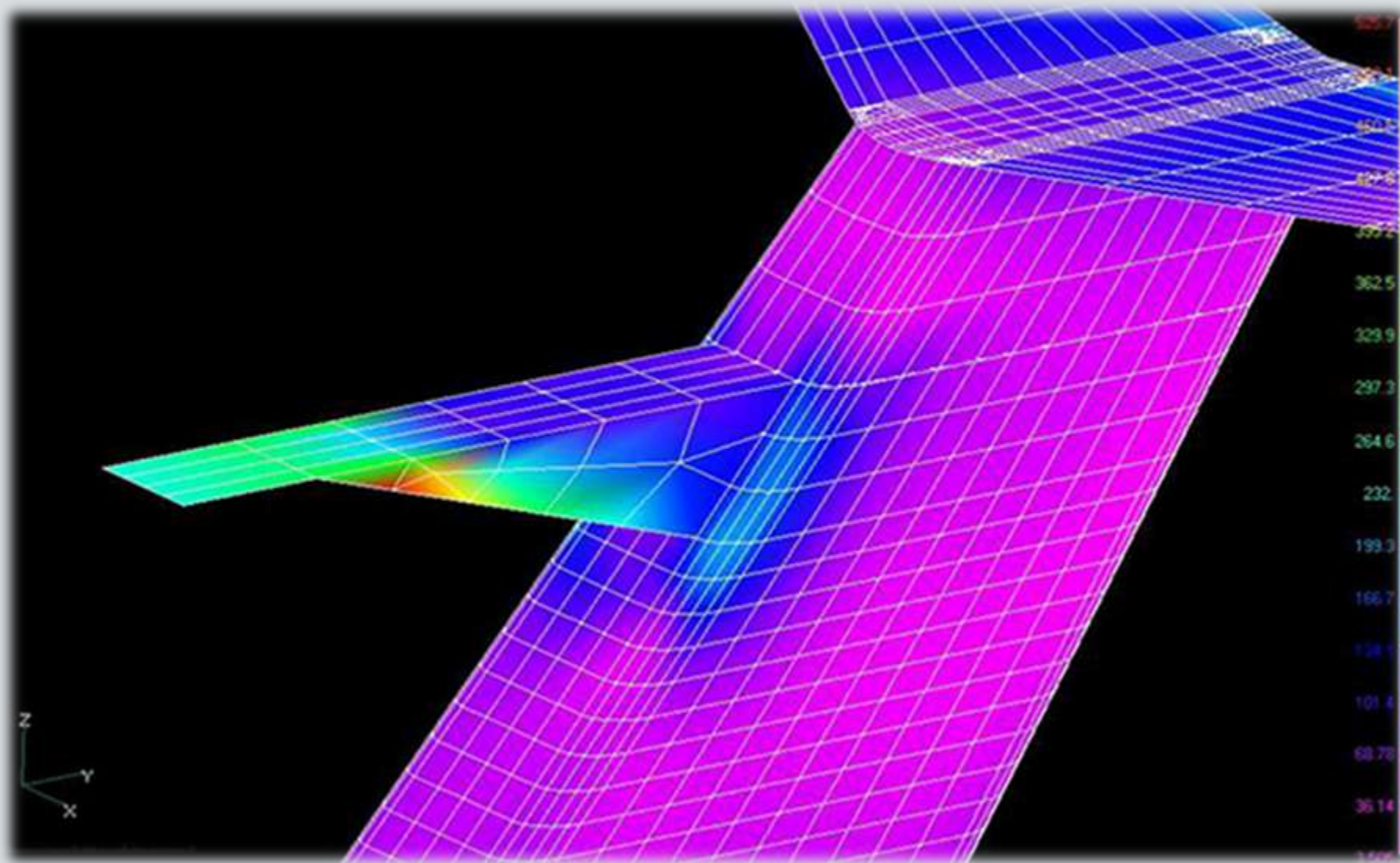


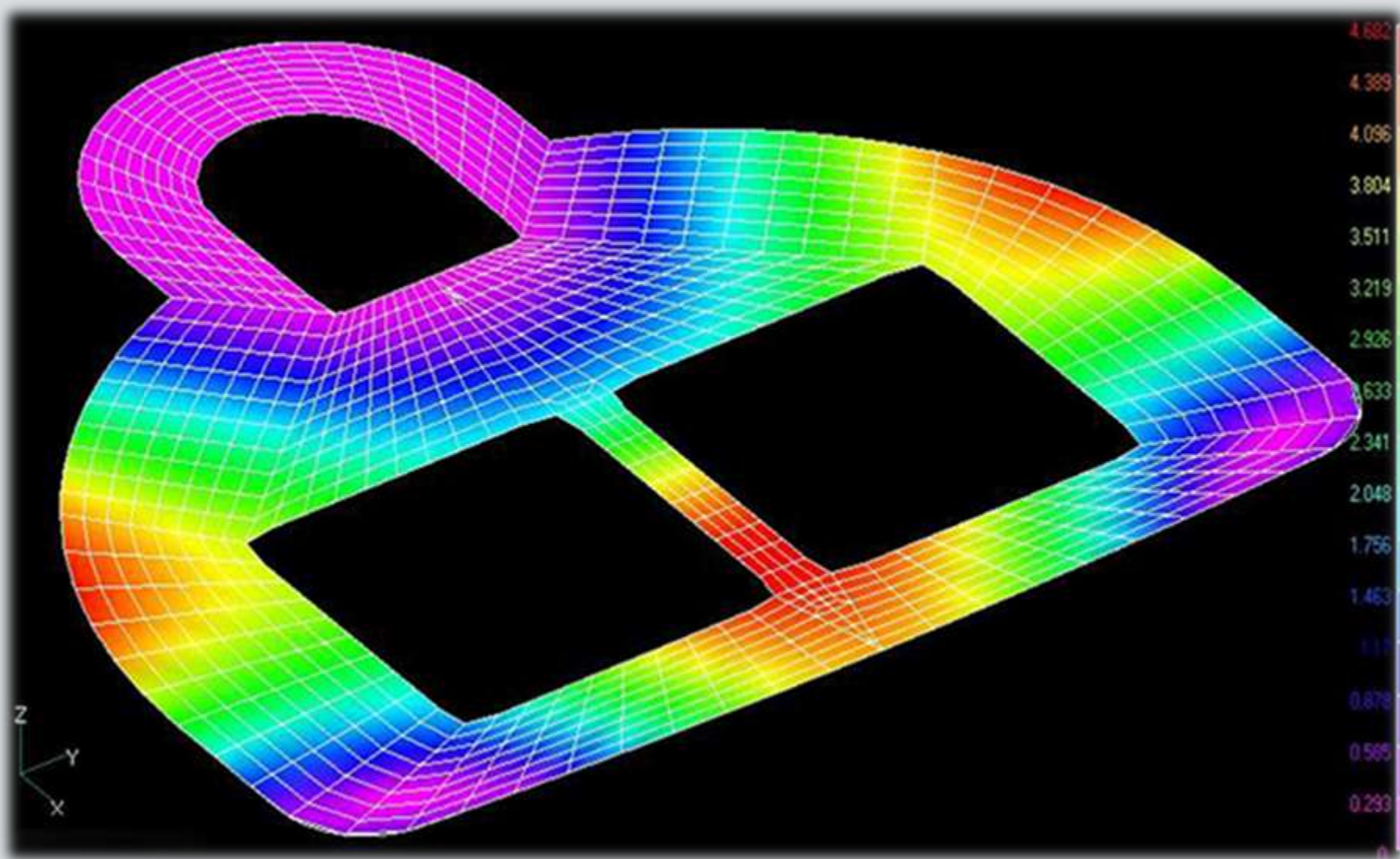


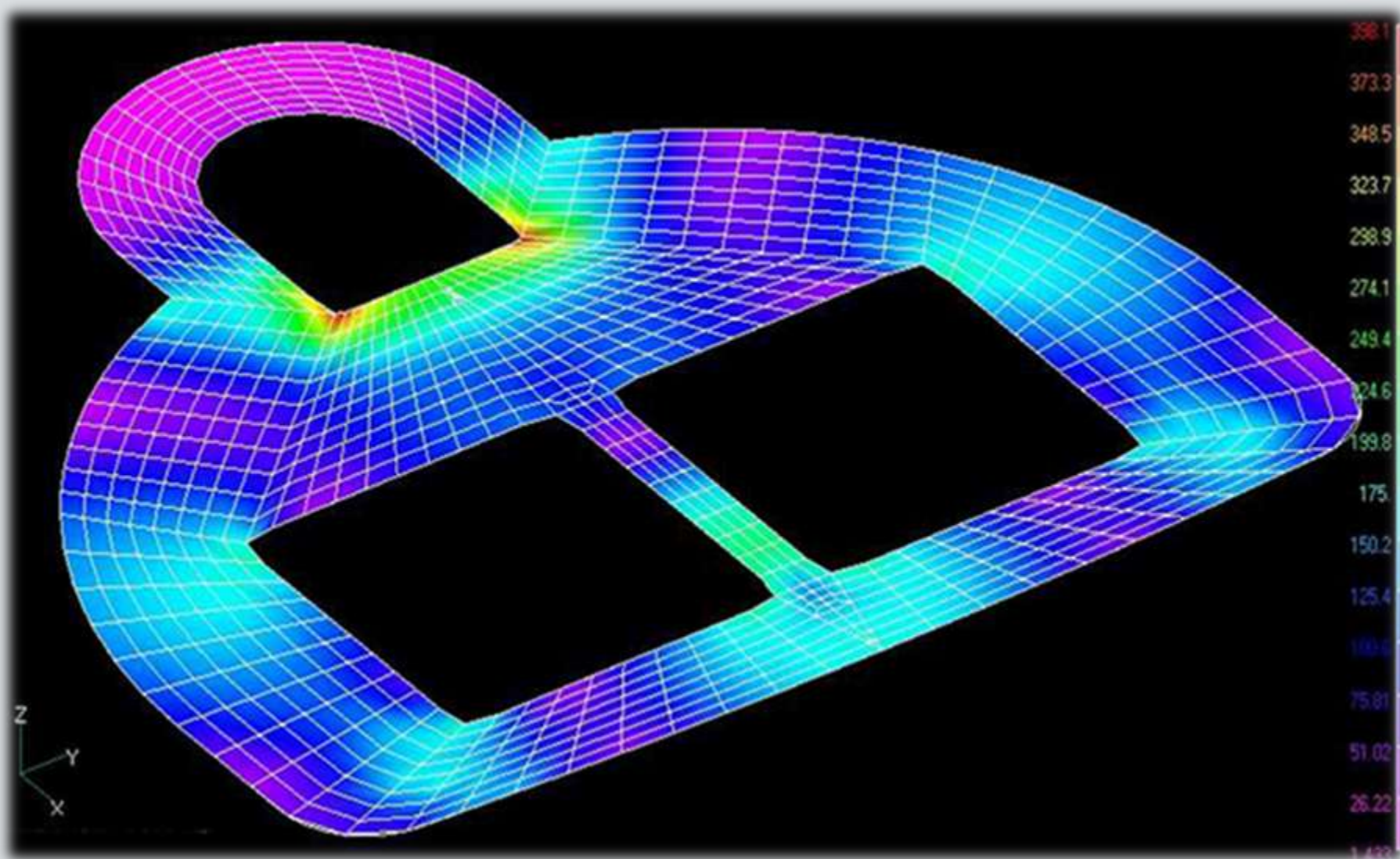


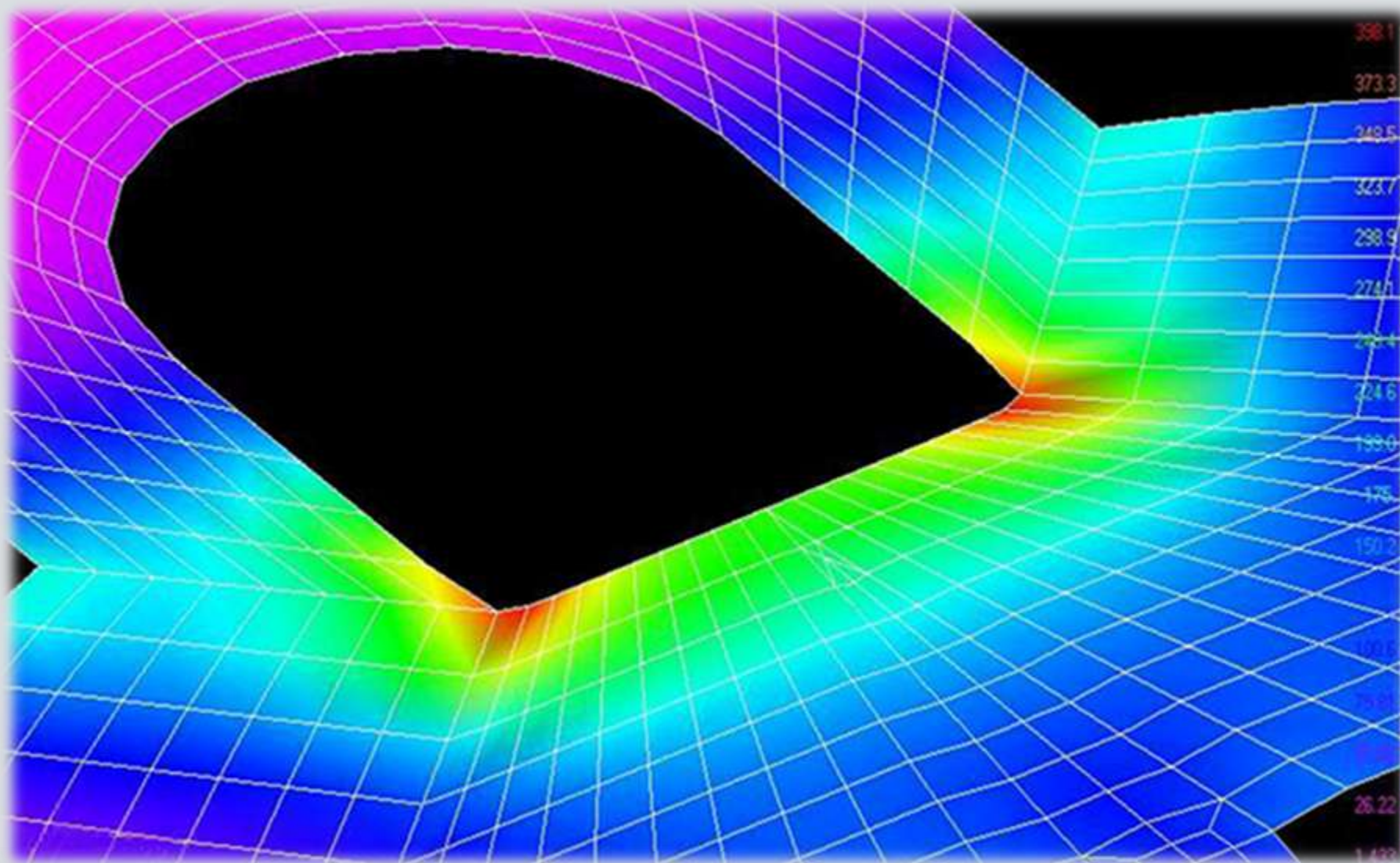












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# Análise de Estruturas Navais em Materiais Compostos pelo Método de Elementos Finitos

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*Jorge Nasseh*