

# *Hybrid Control of a 3-D Structure by using Seismic isolators and Semi-Active Dampers*

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# Goal

During strong seismic ground motions

- ➔ Base isolators shall not rupture
- ➔ Structural response should not be badly affected

Seismic Isolator displacement - Structural displacement



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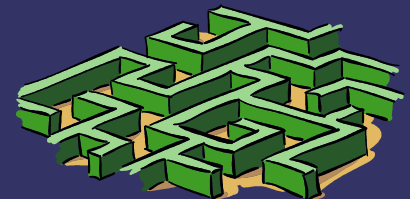
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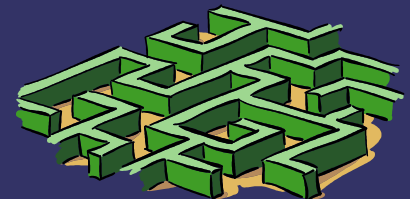
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- ➔ Intro: Control of Seismic isolated Structures
- ➔ 3-story building model
- ➔ semi active hydraulic damper
- ➔ Control Design
  - Linear Quadratic Regulator(LQR)
  - Upper Controller
- ➔ Response simulation
- ➔ Results



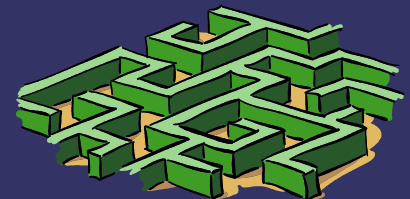
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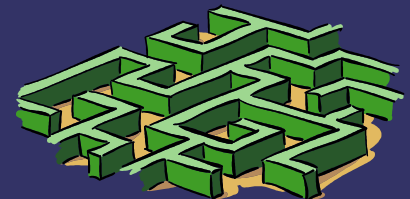
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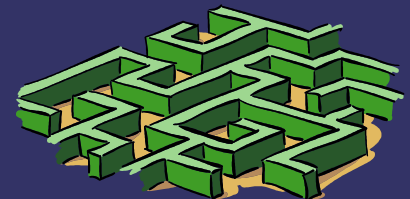
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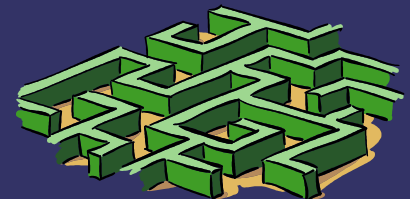
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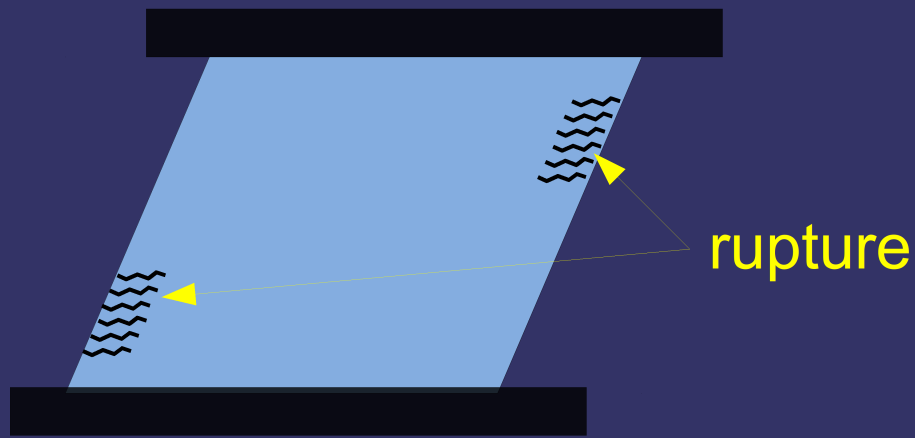
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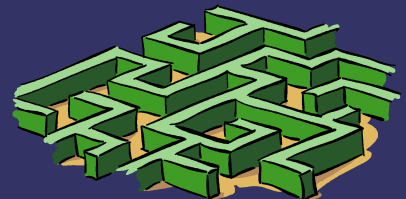
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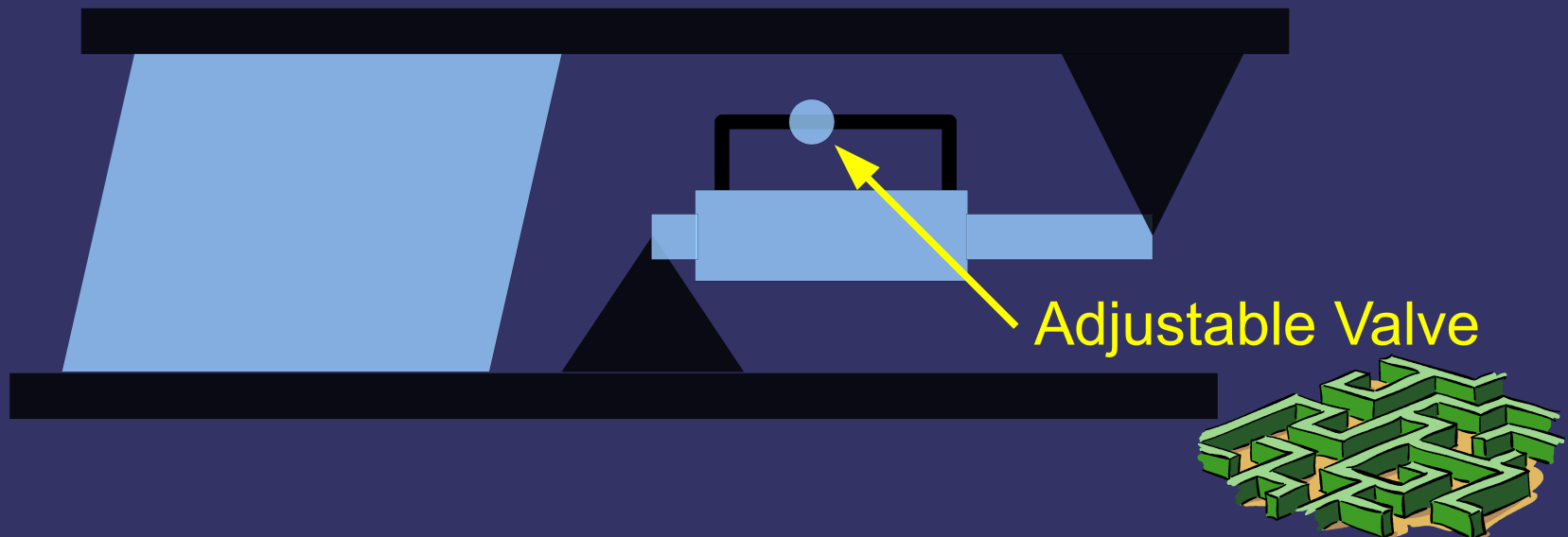
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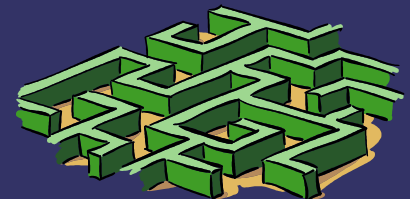
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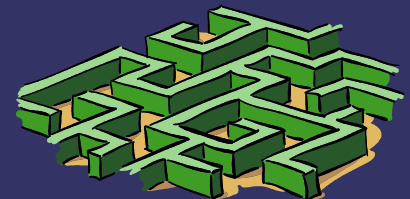
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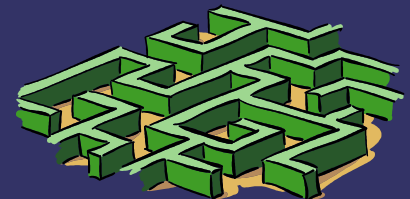
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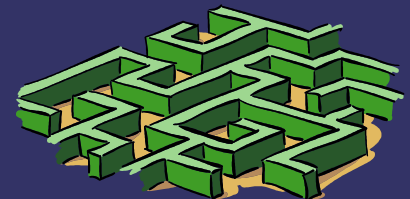
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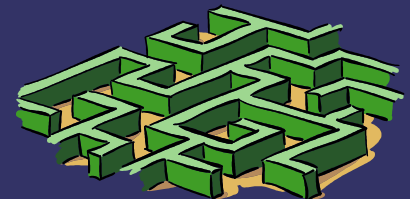
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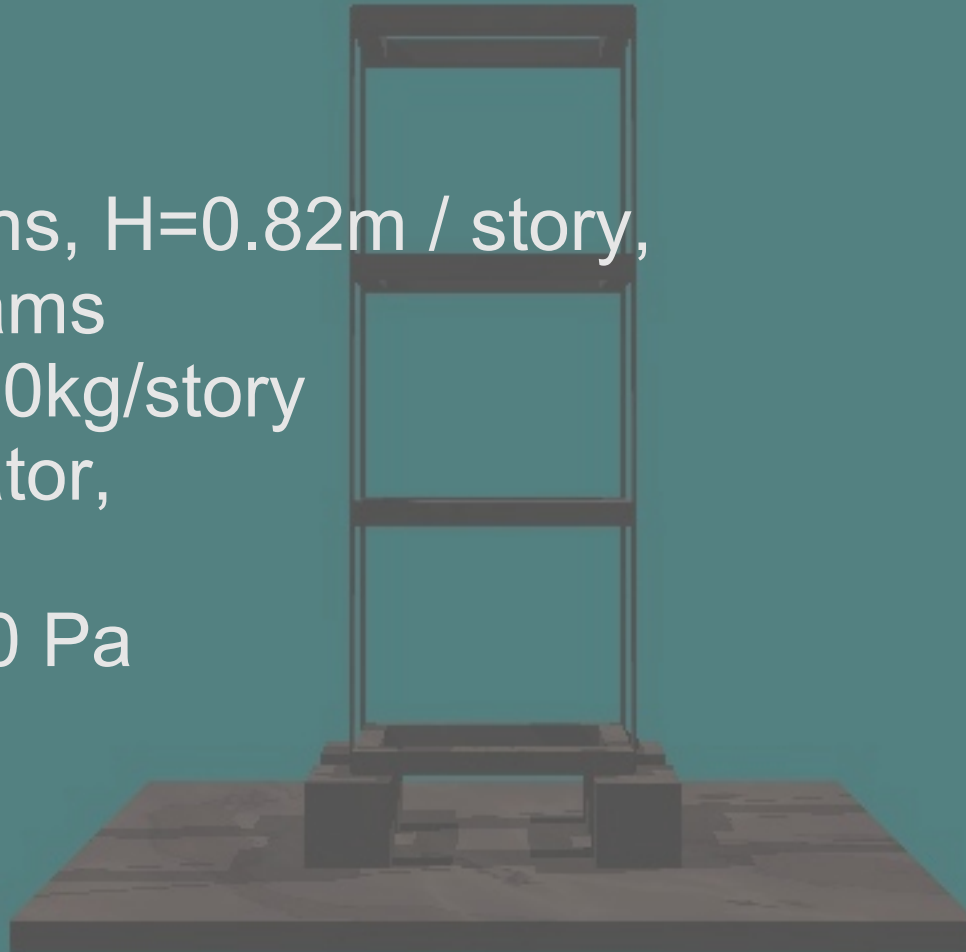
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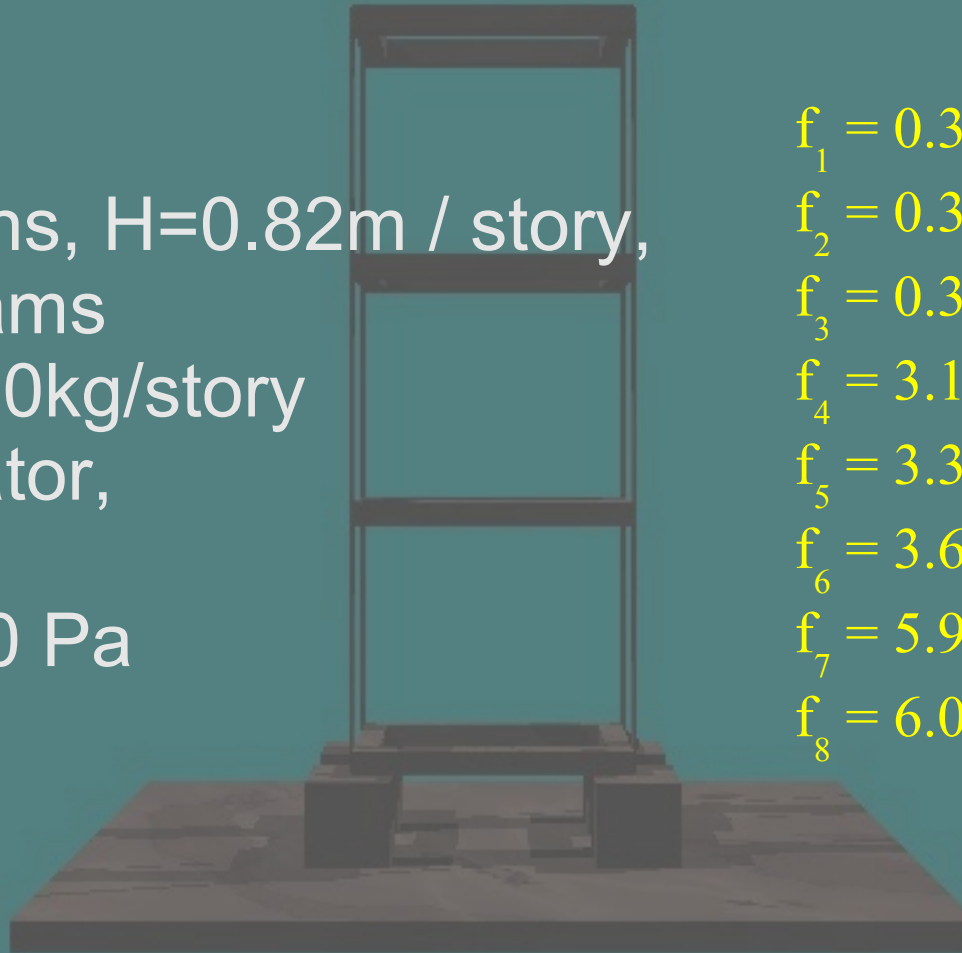
# *Building Model*

- ➔ 3 stories
  - 4 columns,  $H=0.82\text{m}$  / story,
  - rigid beams
  - Mass  $200\text{kg}/\text{story}$
- ➔ Seismic isolator,
  - $H=4\text{cm}$
  - $E_y = 4000\text{ Pa}$



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$$f_1 = 0.31 \text{ Hz}$$

$$f_2 = 0.32 \text{ Hz}$$

$$f_3 = 0.34 \text{ Hz}$$

$$f_4 = 3.11 \text{ Hz}$$

$$f_5 = 3.33 \text{ Hz}$$

$$f_6 = 3.60 \text{ Hz}$$

$$f_7 = 5.92 \text{ Hz}$$

$$f_8 = 6.05 \text{ Hz}$$

$$f_9 = 6.68 \text{ Hz}$$

$$f_{10} = 7.60 \text{ Hz}$$

$$f_{11} = 8.02 \text{ Hz}$$

$$f_{12} = 9.22 \text{ Hz}$$

$$f_{13} = 111.00 \text{ Hz}$$

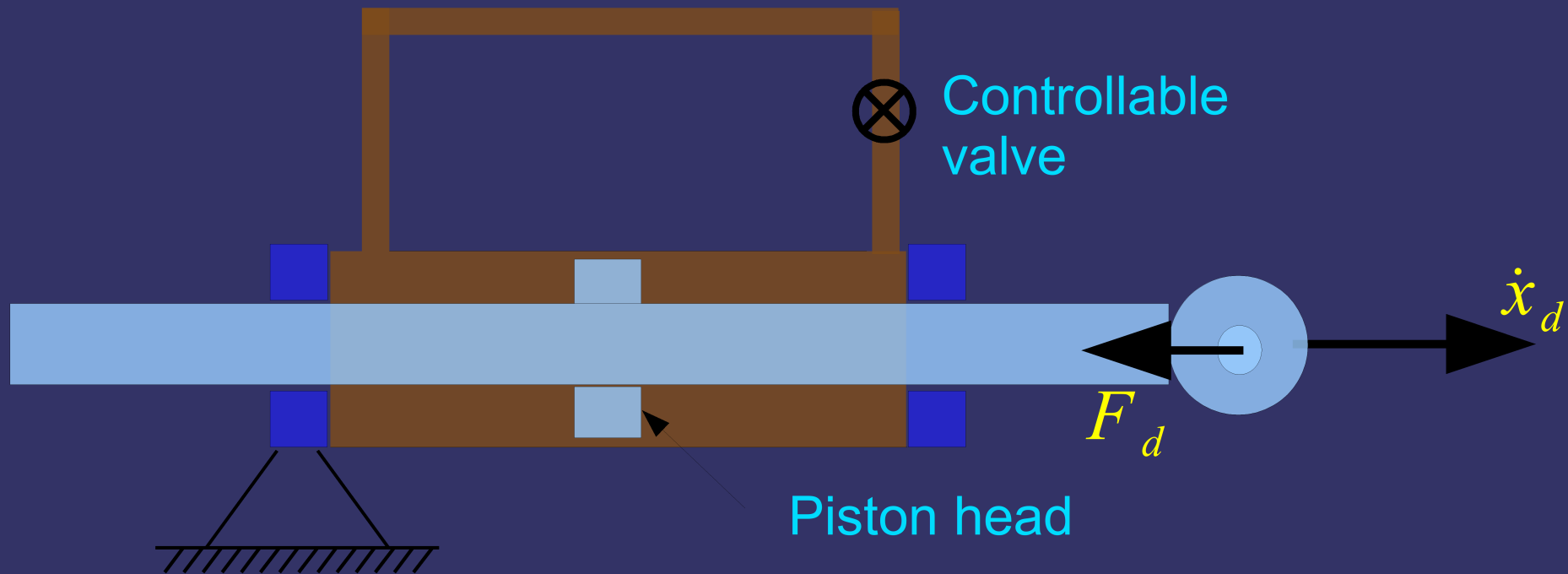
$$f_{14} = 111.80 \text{ Hz}$$

$$f_{15} = 112.50 \text{ Hz}$$

$$f_{16} = 124.50 \text{ Hz}$$



# *Damper with adjustable valve (semi active damper)*



$$F_d \approx -c_d \dot{x}_d$$

$$5000 \frac{N \cdot s}{m} < c_d < 25000 \frac{N \cdot s}{m}$$

# *Control Design: Linear Quadratic Regulator (LQR)*

$$M \ddot{x} + (C + \Gamma_d C_d \Gamma_d^T) \dot{x} + K x = -M \Gamma_{eq} \ddot{x}_{eq}$$



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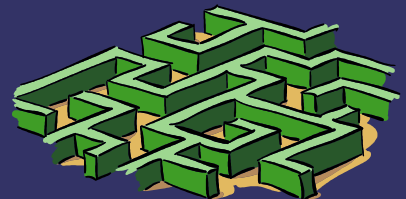
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2nd order diff. Equation --> 1st order diff.Eqn.

$$\dot{q} = A q + B_1 \ddot{x}_g + B_2 u$$



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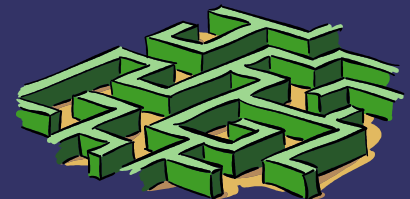
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$$\dot{q} = A q + B_1 \ddot{x}_g + B_2 u$$

Here,  $q = \begin{bmatrix} x & \dot{x} \end{bmatrix}^T$

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}(C + \Gamma_d C_d \Gamma_d^T) \end{bmatrix} \quad B_1 = \begin{bmatrix} 0 \\ \Gamma_{eq} \end{bmatrix} \quad B_2 = \begin{bmatrix} 0 \\ M^{-1} \Gamma_d \end{bmatrix}$$



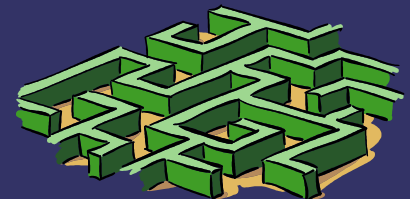
# Control Design: (LQR)

Minimization problem

$$V(q) = \int_0^{\infty} \underbrace{q^T Q q}_{\text{Structural response contribution}} + \underbrace{u^T R u}_{\text{Control force contribution}} dt$$

Control force  
contribution

Structural response  
contribution



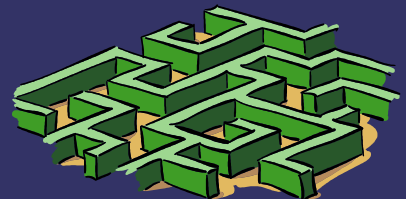
# ***Control Design: (LQR)***

The optimal control force that minimizes the problem definition

$$u^o = -R^{-1} B_2^T \bar{P} q^o$$

Here,  $\bar{P}$  is the solution to the following Ricatti equation

$$A^T \bar{P} + \bar{P} A + Q - \bar{P} B_2 R^{-1} B_2^T \bar{P} = 0$$

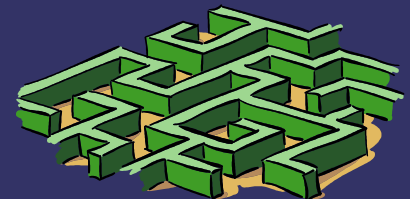


# *Control Design: Upper Controller*

- ➔ Damping levels: 5000 : 5000 : 25000 Ns/m  
5 positions / damper
- ➔ No. of dampers = 4

Therefore

- ➔ 625 damping configurations, and thus
- ➔ 625 optimal control equations  
(The minimization problem is solved for 625 different configurations)



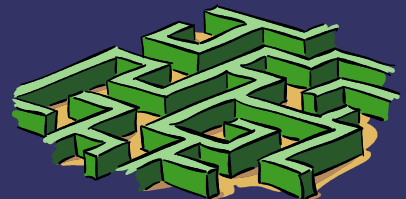


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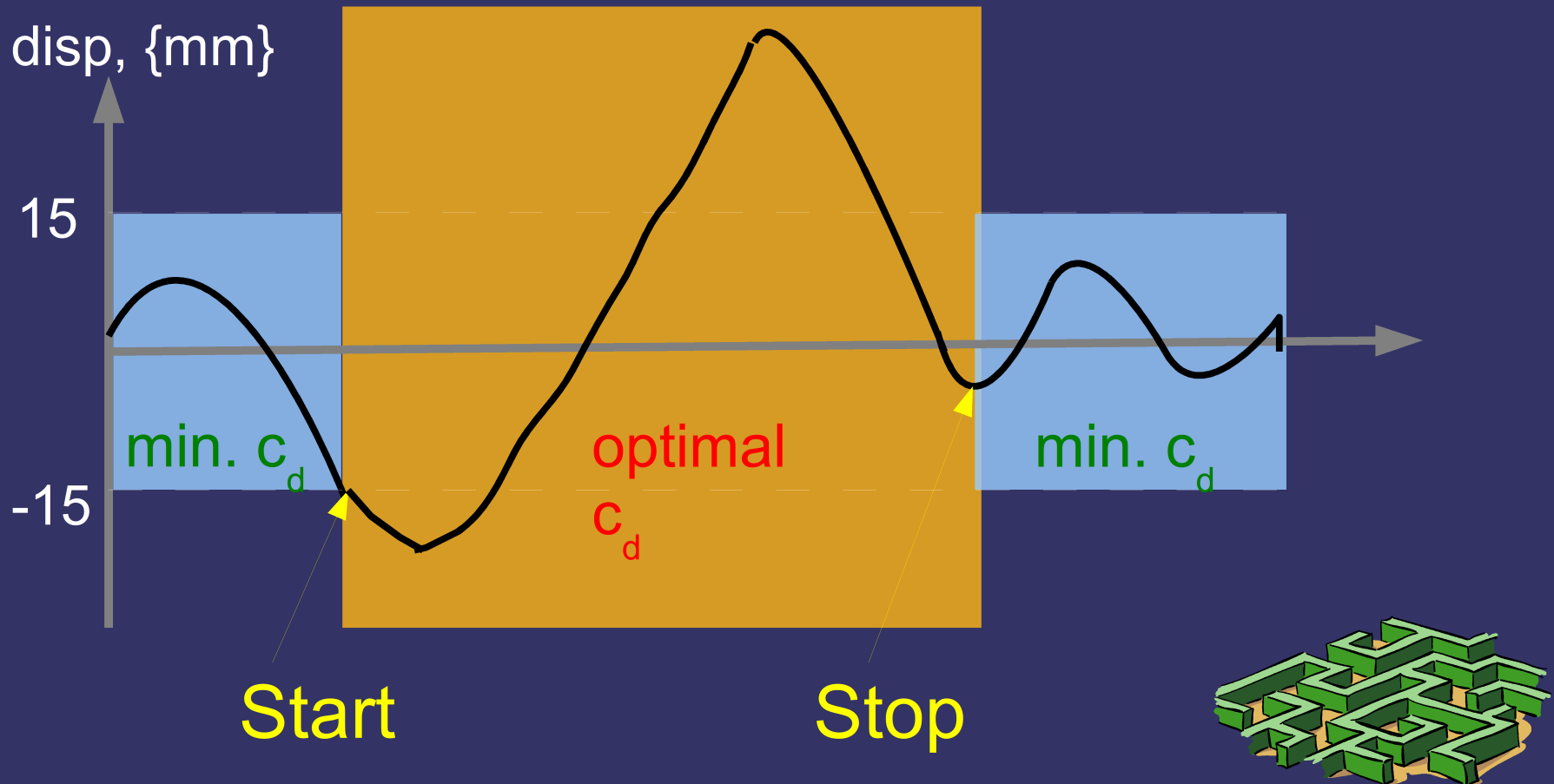
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- ⇒  $d_{\text{base}} < 15\text{mm} \rightarrow$  minimum damping
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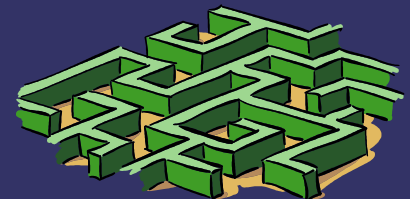
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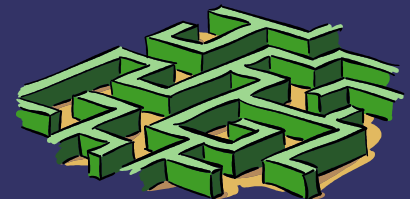
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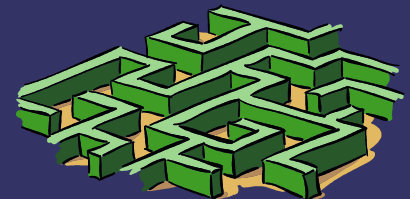
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# Response simulation

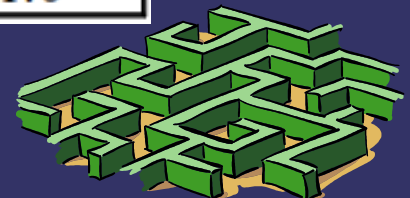
## Selected Earthquakes

19.05.1940 Imperial Valley (El Centro)

12.11.1999 Düzce (Bolu)

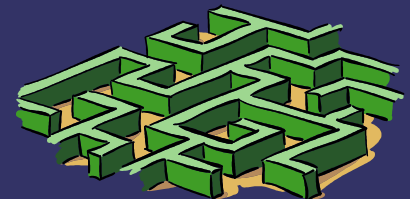
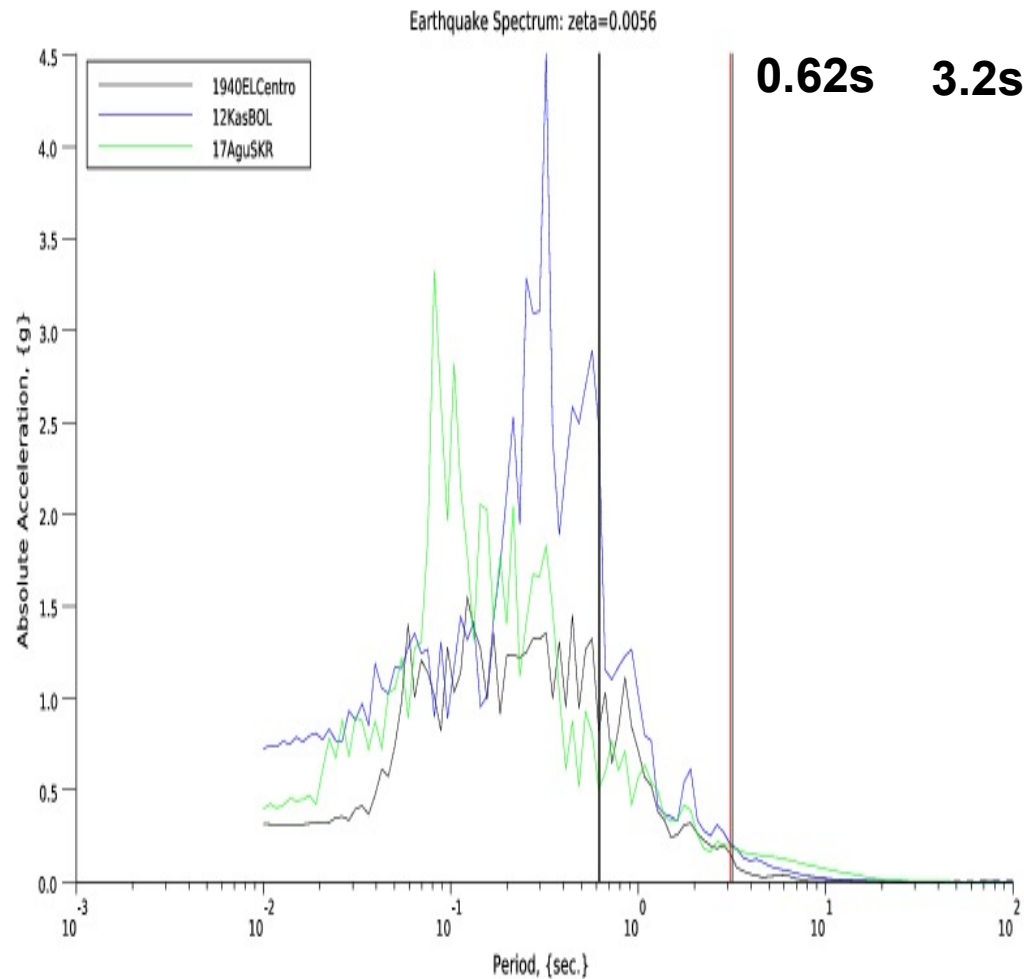
17.08.1999 Kocaeli (Sakarya)

Earthquake		Date	$A_{\max},$ {g}	$V_{\max},$ {m/s}	$D_{\max},$ {m}
1	I-ELC-180	1940	0.296	0.236	0.130
	I-ELC-270	1940	0.179	0.279	0.221
2	Bolu-000	1999	0.728	0.405	0.230
	Bolu-090	1999	0.822	0.620	0.132
3	SKR-090	1999	0.317	0.284	0.442
4	I-ELC-180-DF	-	0.304	1.18	3.25
	I-ELC-270-DF	-	0.182	1.39	5.51
5	Bolu-000-DF	-	0.733	2.03	5.74
	Bolu-090-DF	-	0.830	3.10	3.30
6	SKR-090-DF	-	0.337	1.42	11.0



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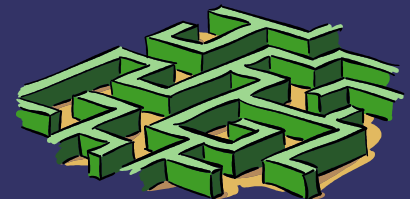
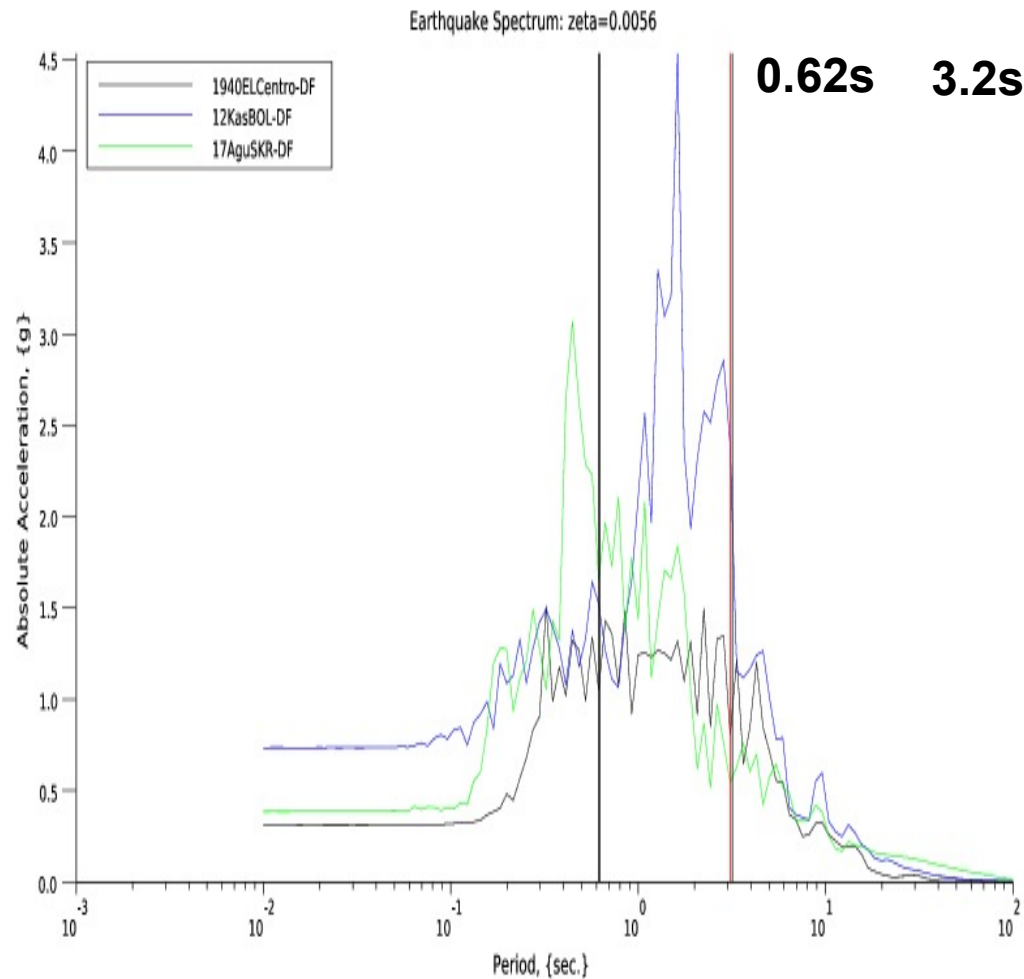
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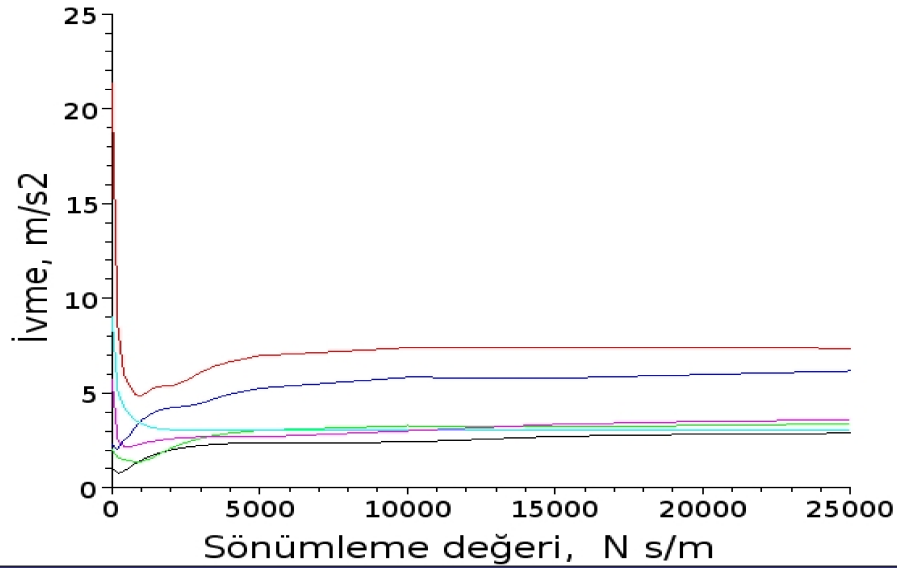
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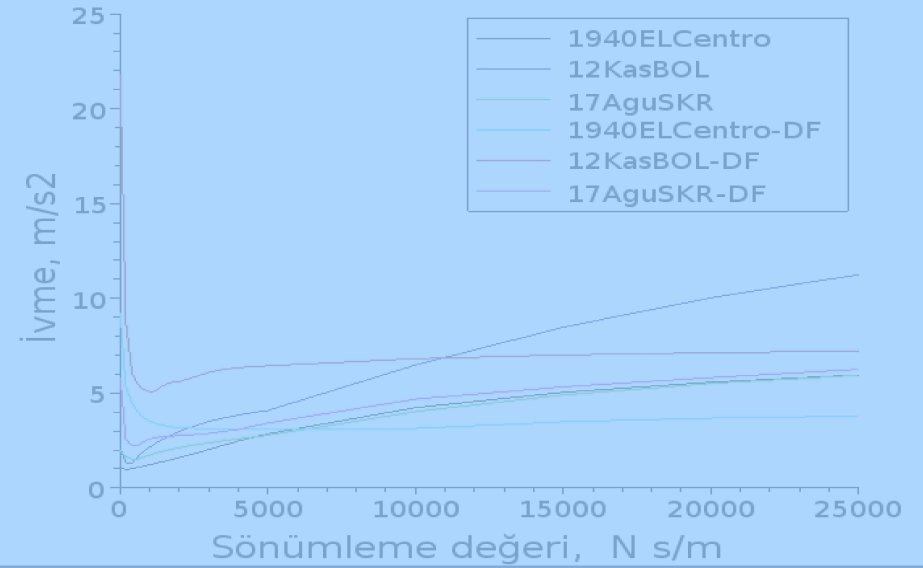


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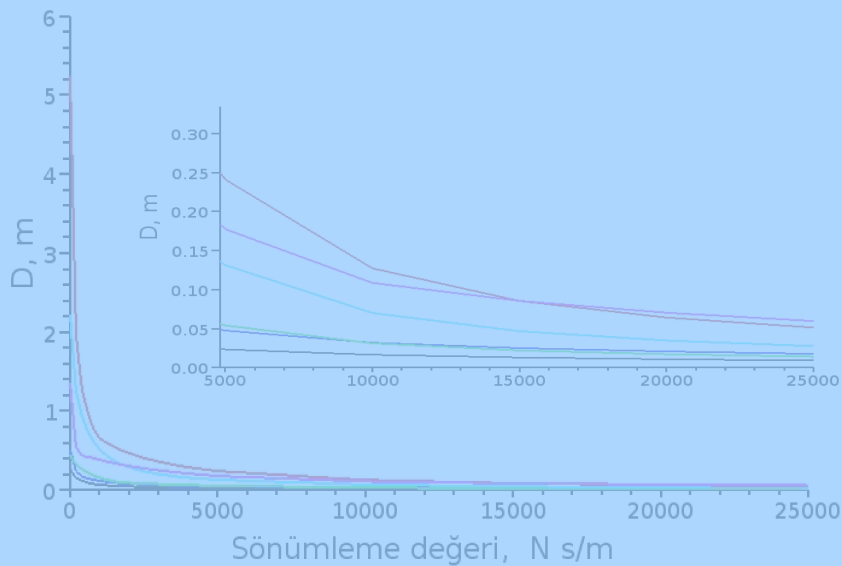
Taban ivme Davranışı



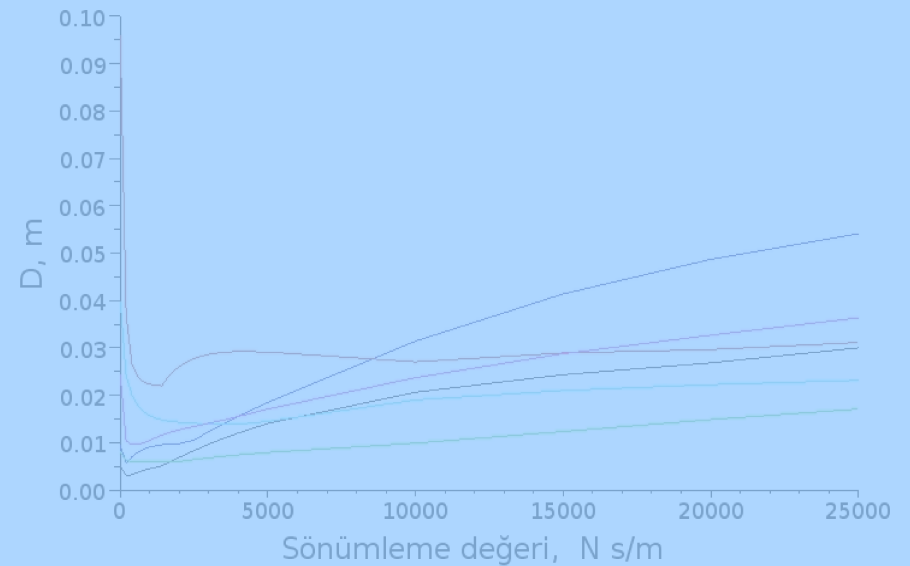
1.Kat ivme Davranışı



Taban deplasman Davranışı

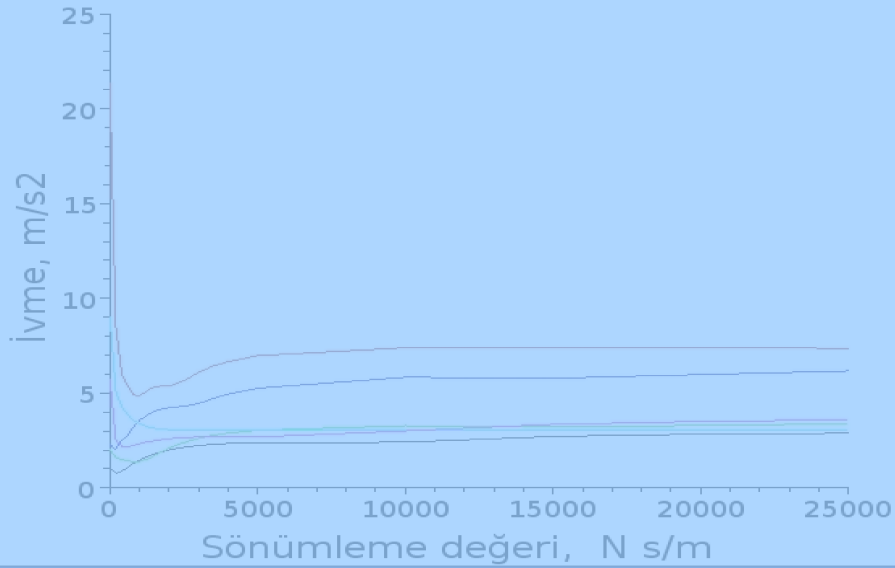


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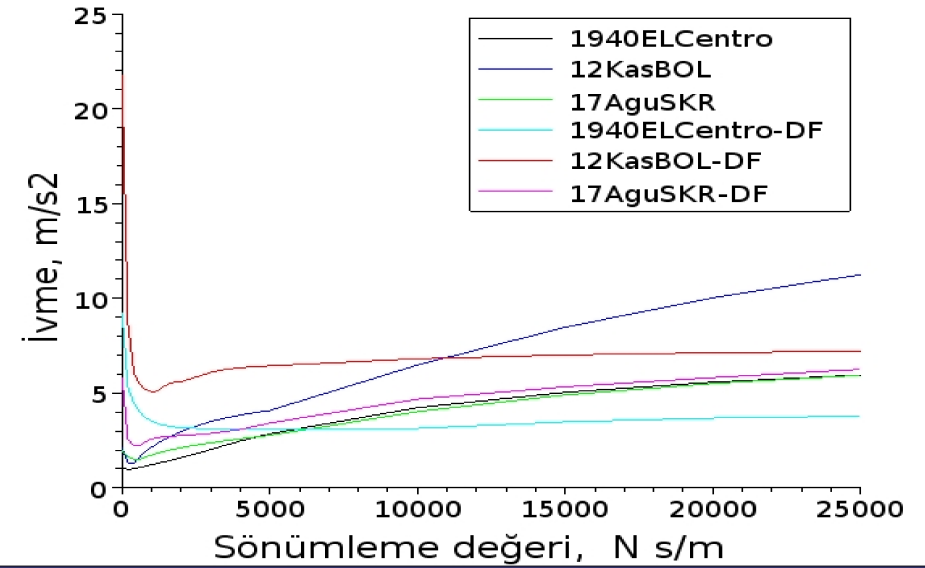


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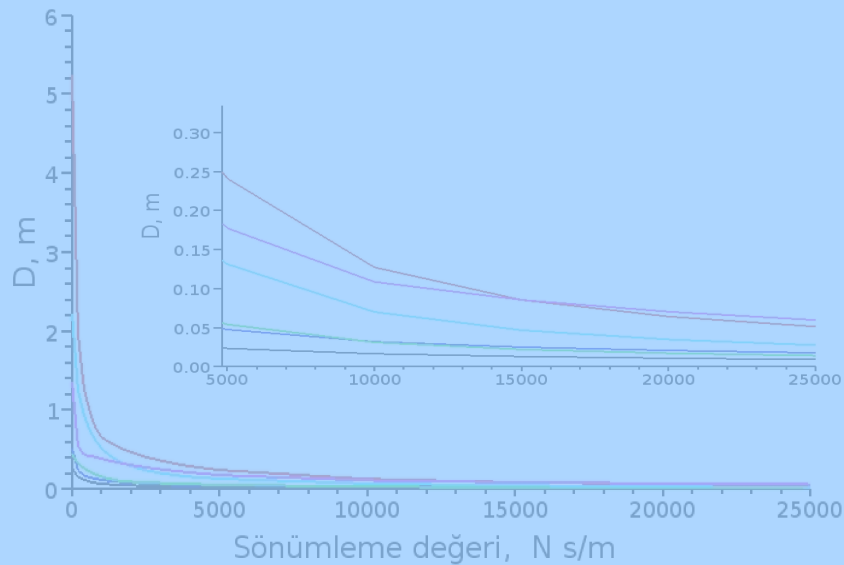
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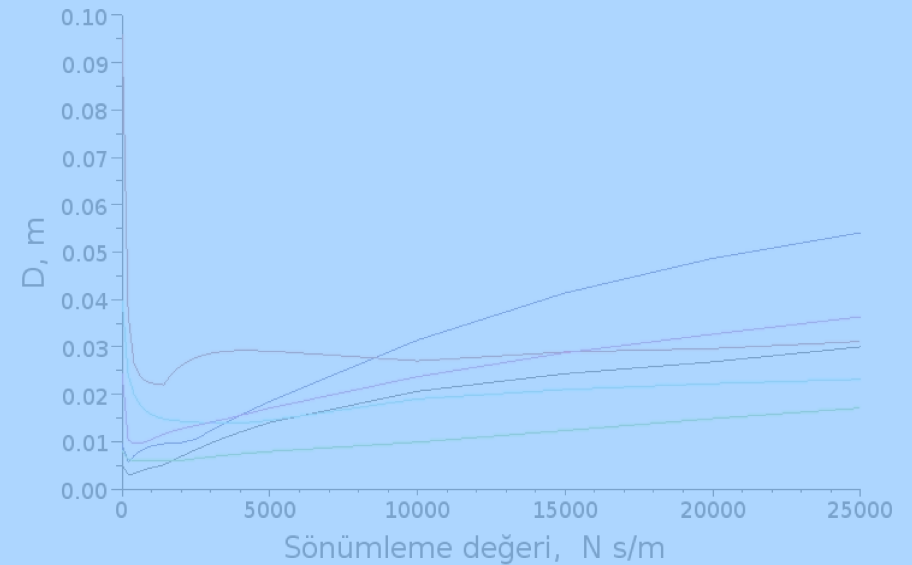
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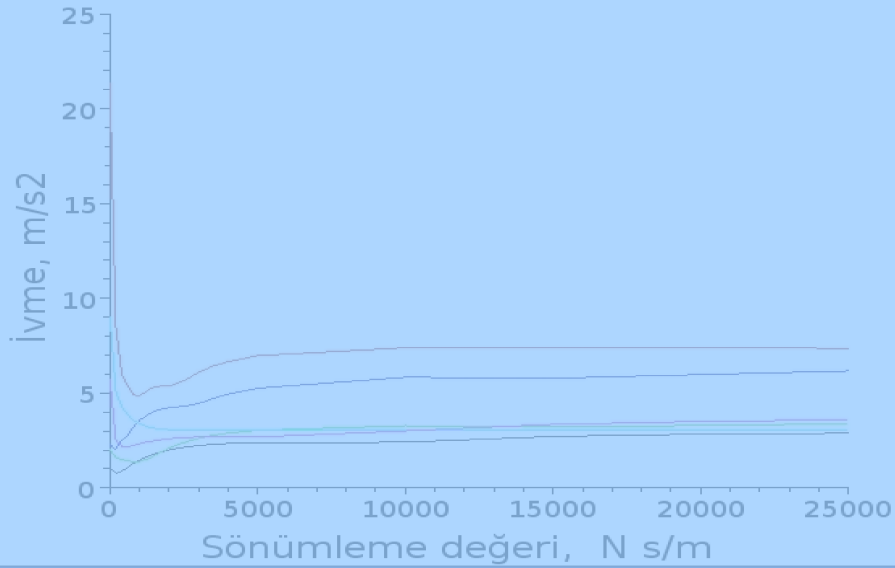


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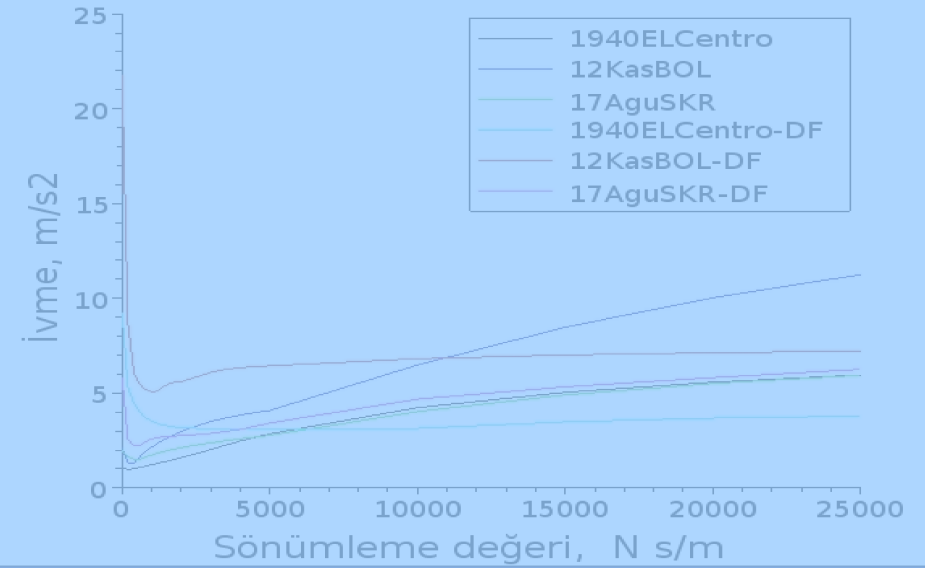


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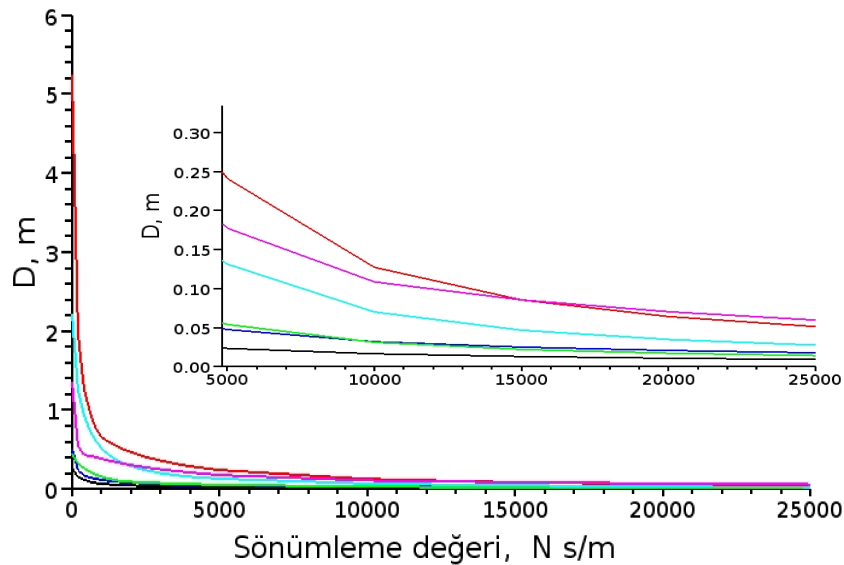
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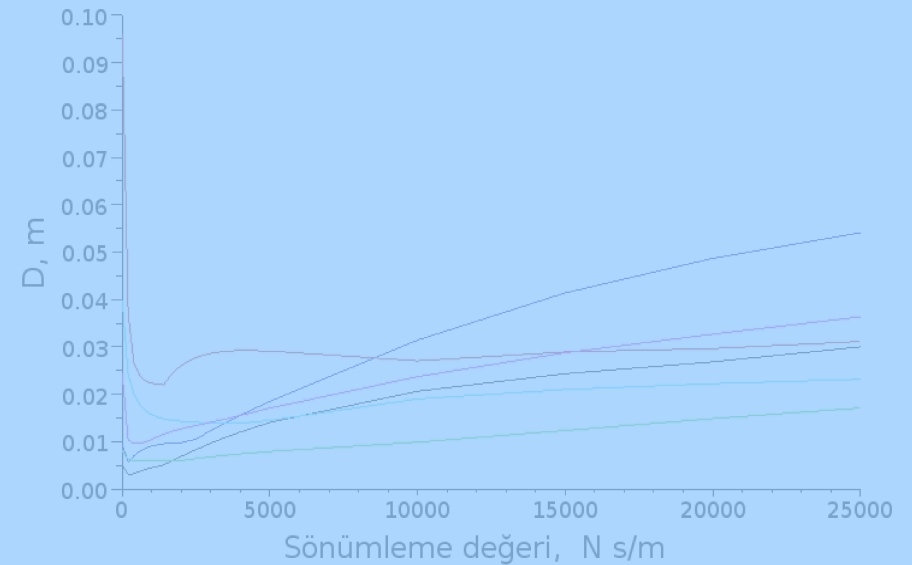
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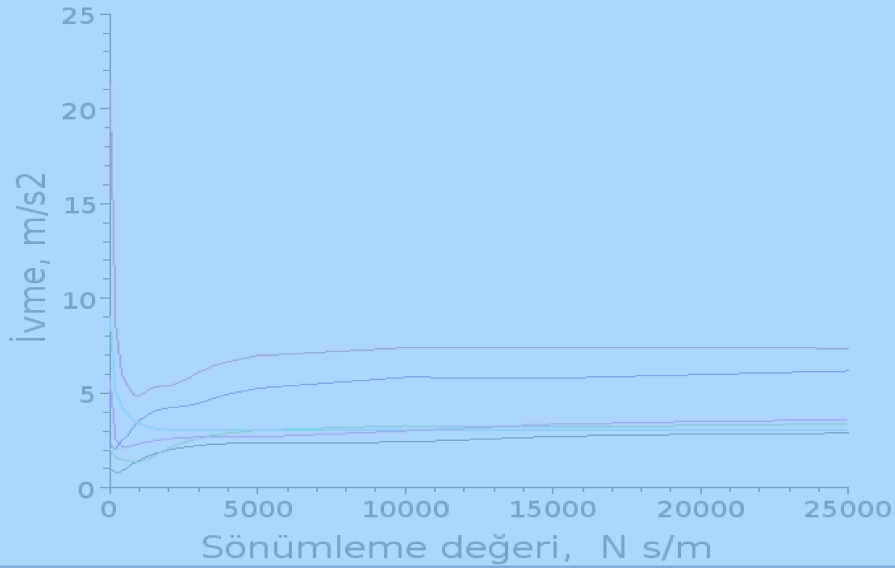


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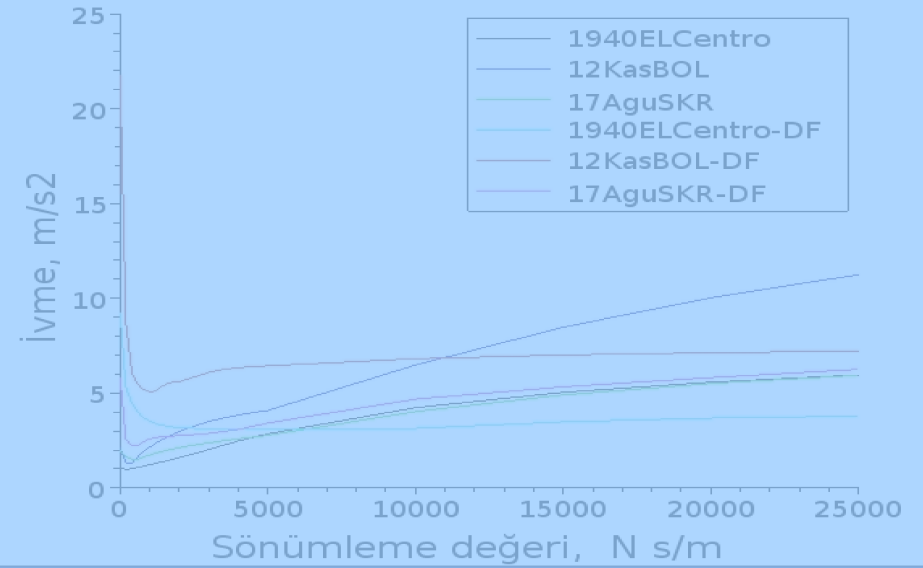


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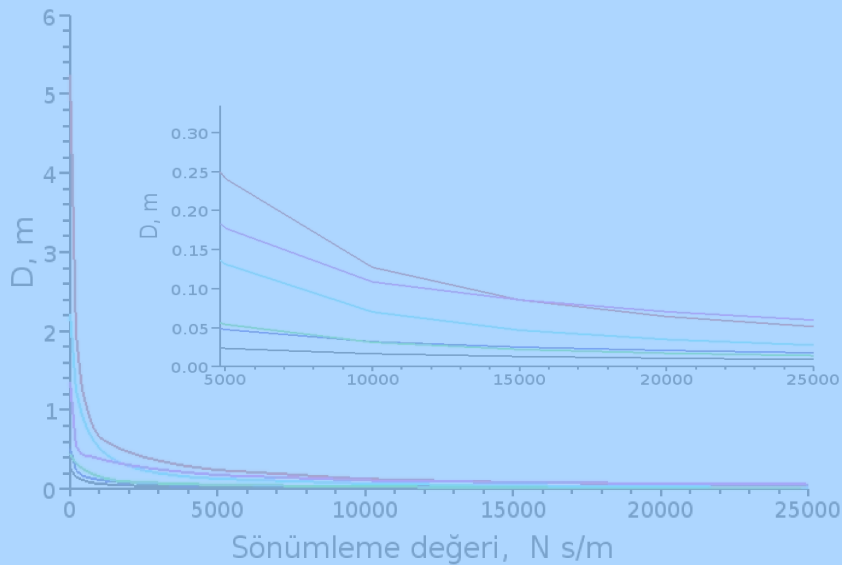
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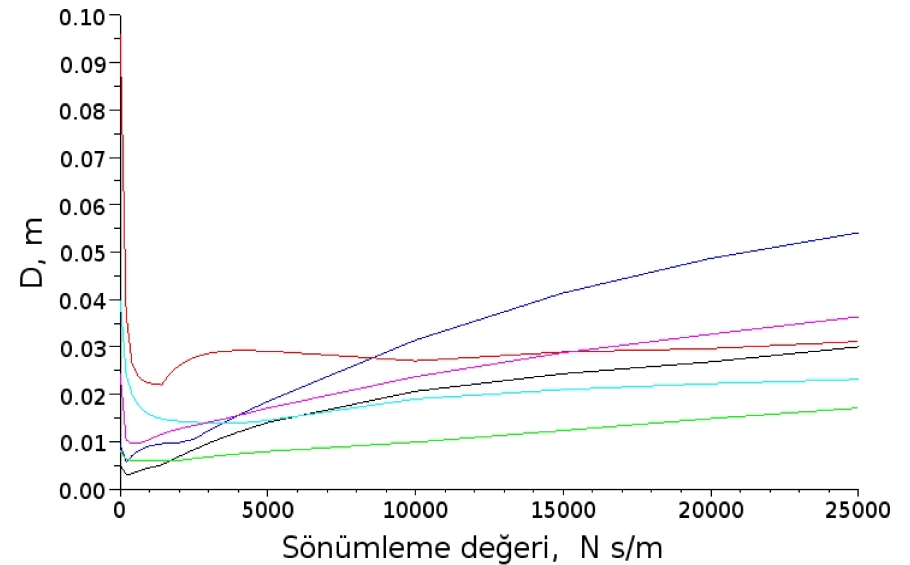
1.Kat ivme Davranışı



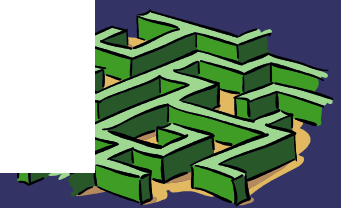
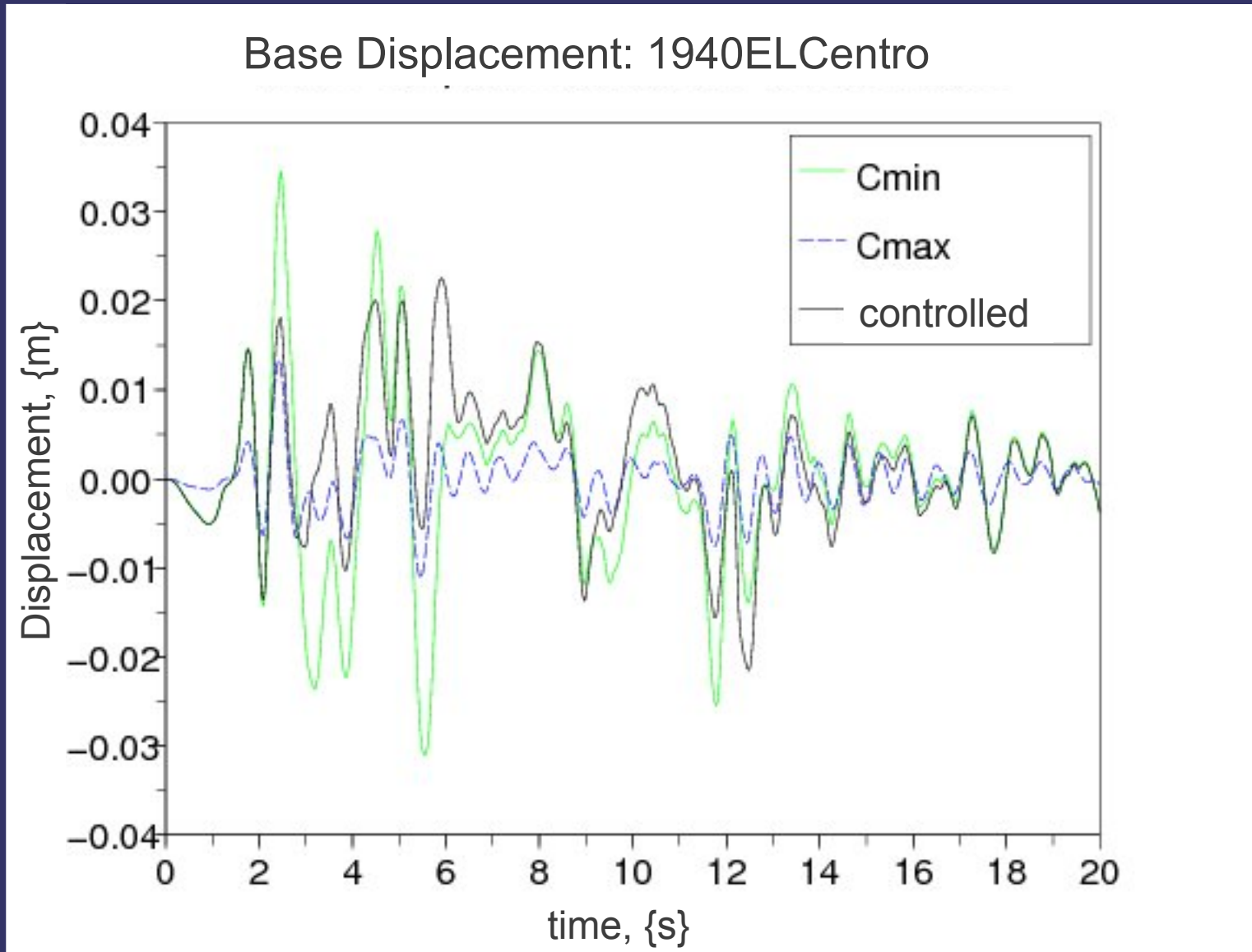
Taban deplasman Davranışı



1.Kat deplasman Davranışı

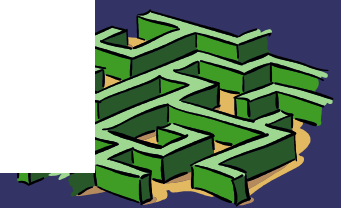
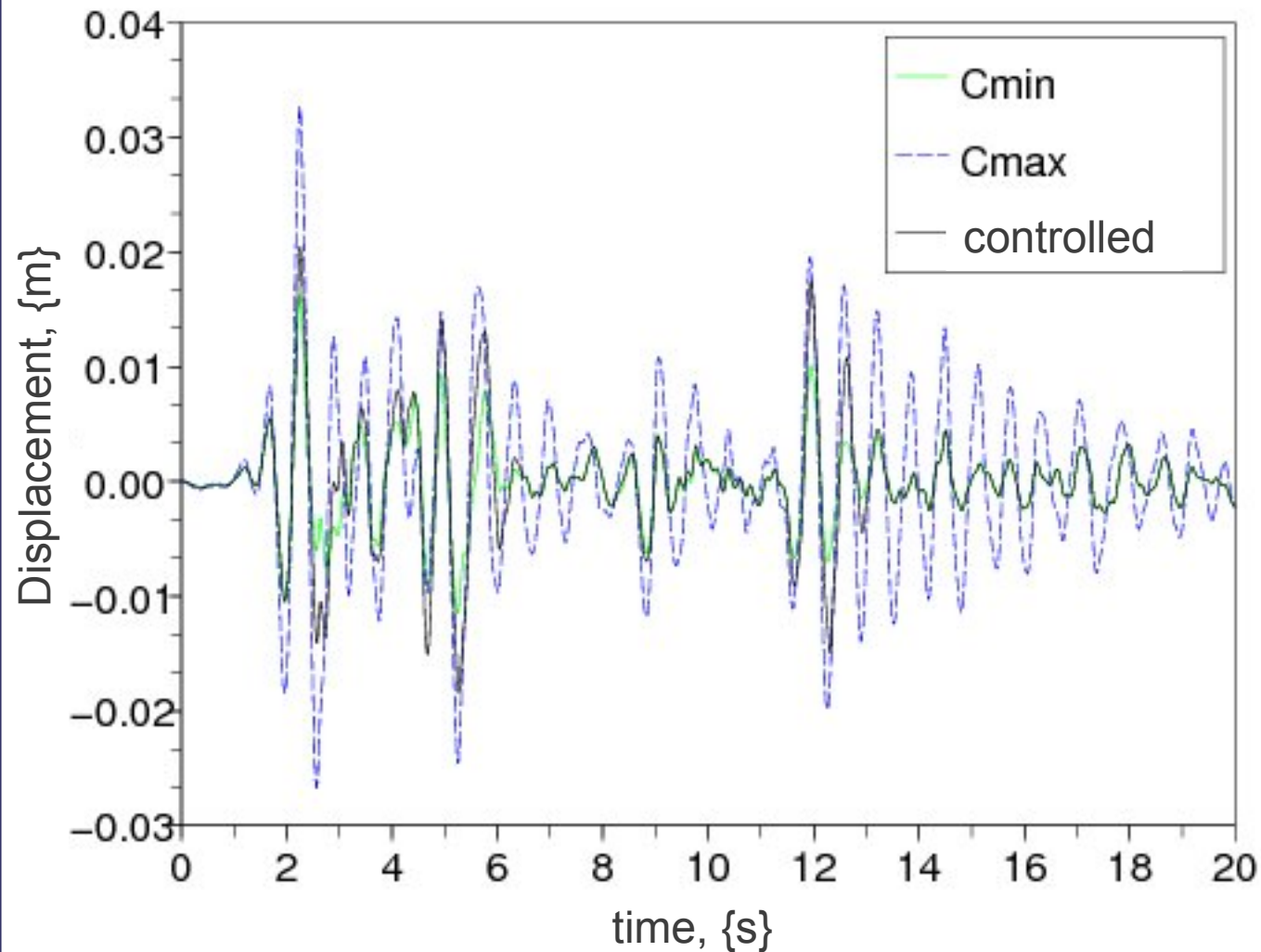


# *Response simulation*



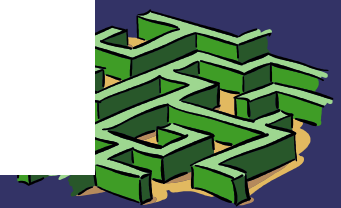
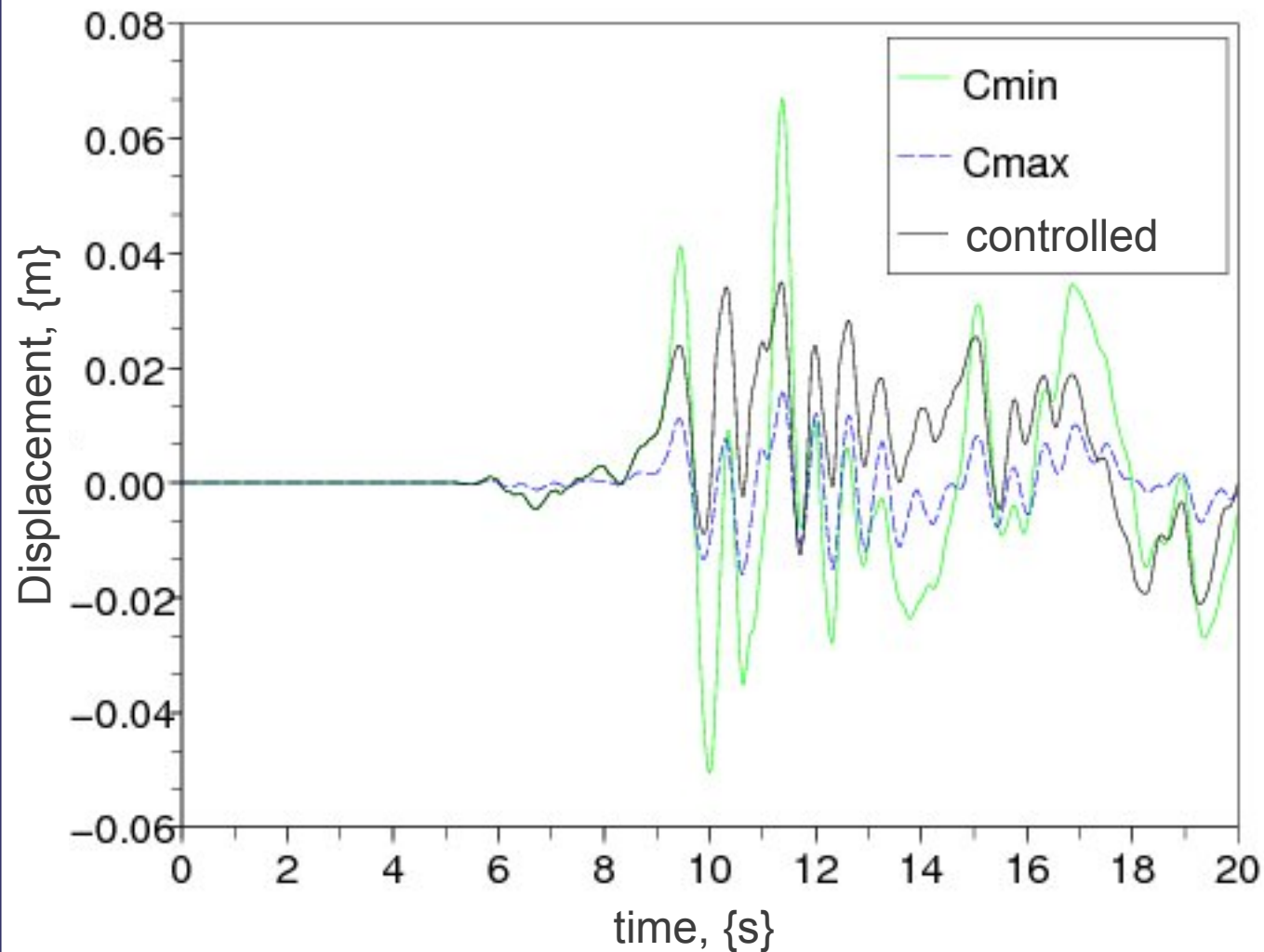
# *Response simulation*

1st story Displacement: 1940ELCentro



# *Response simulation*

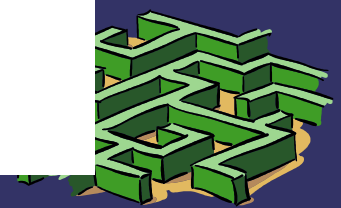
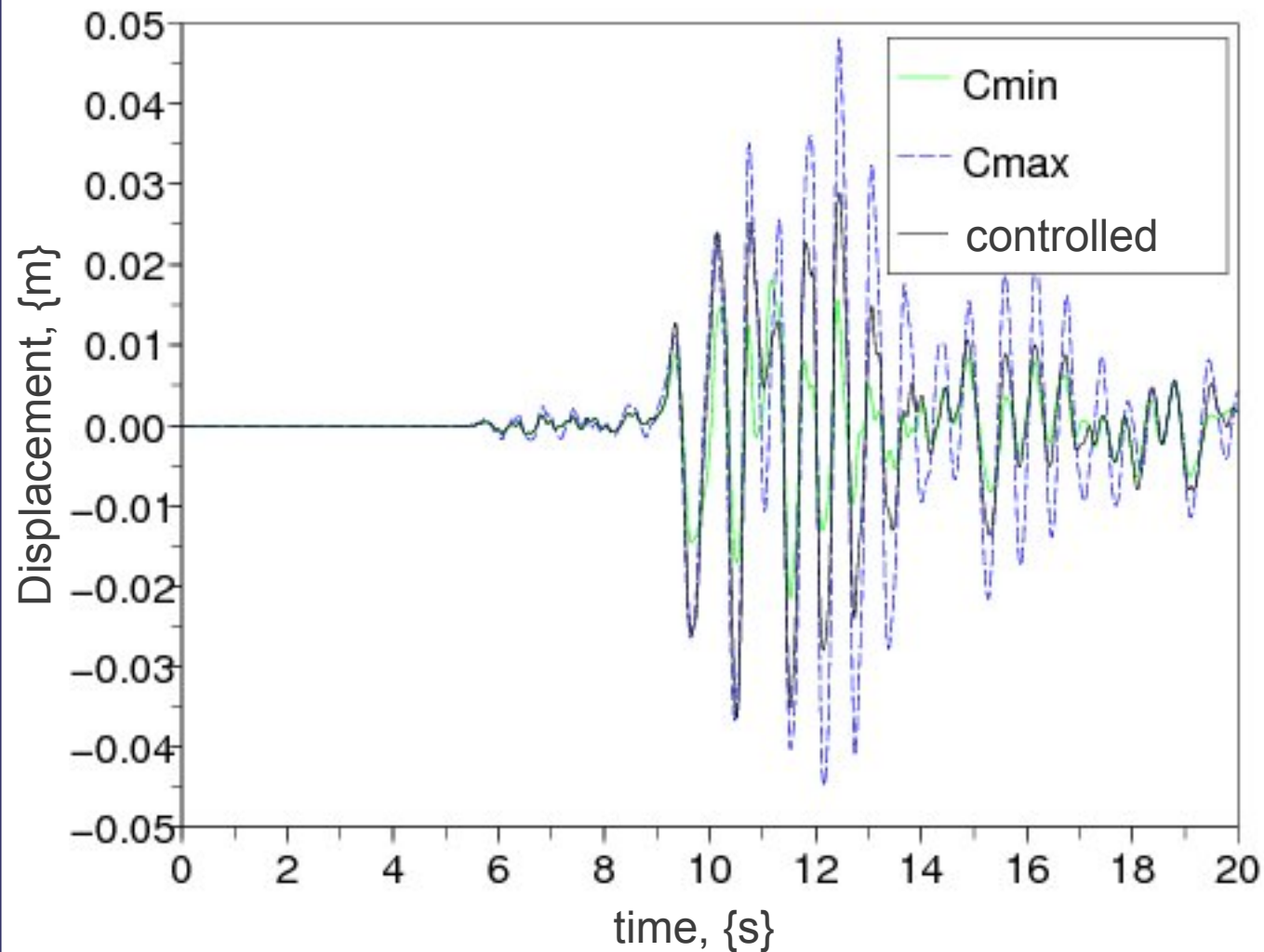
Base Displacement: 12KasBolu



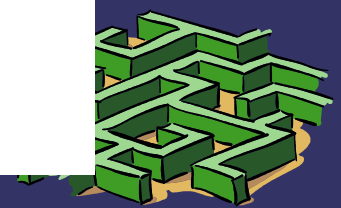
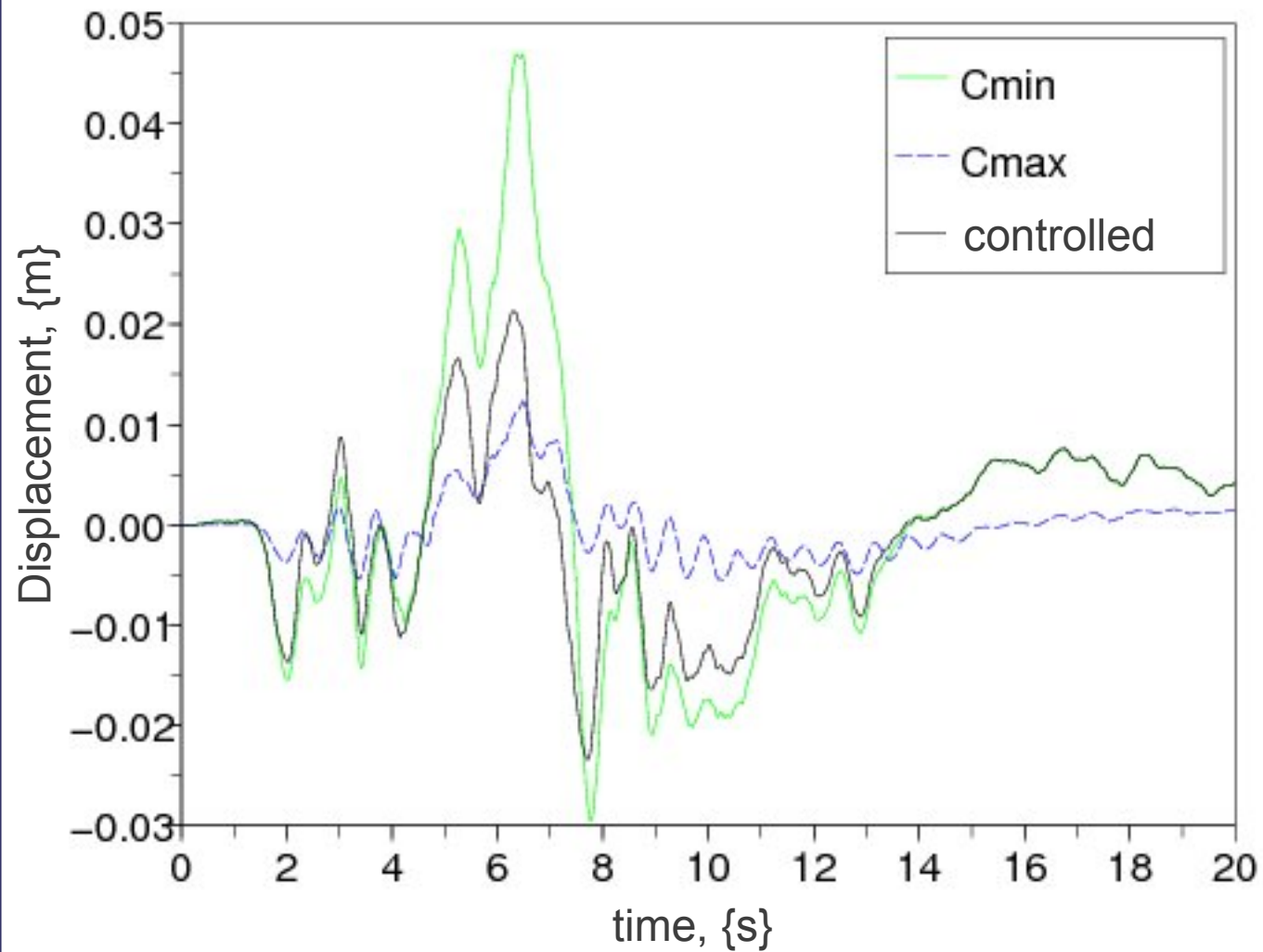


# *Response simulation*

1st story Displacement: 12KasBolu

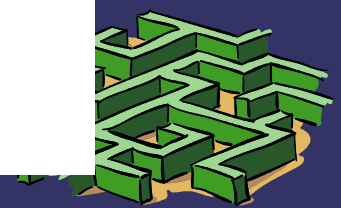
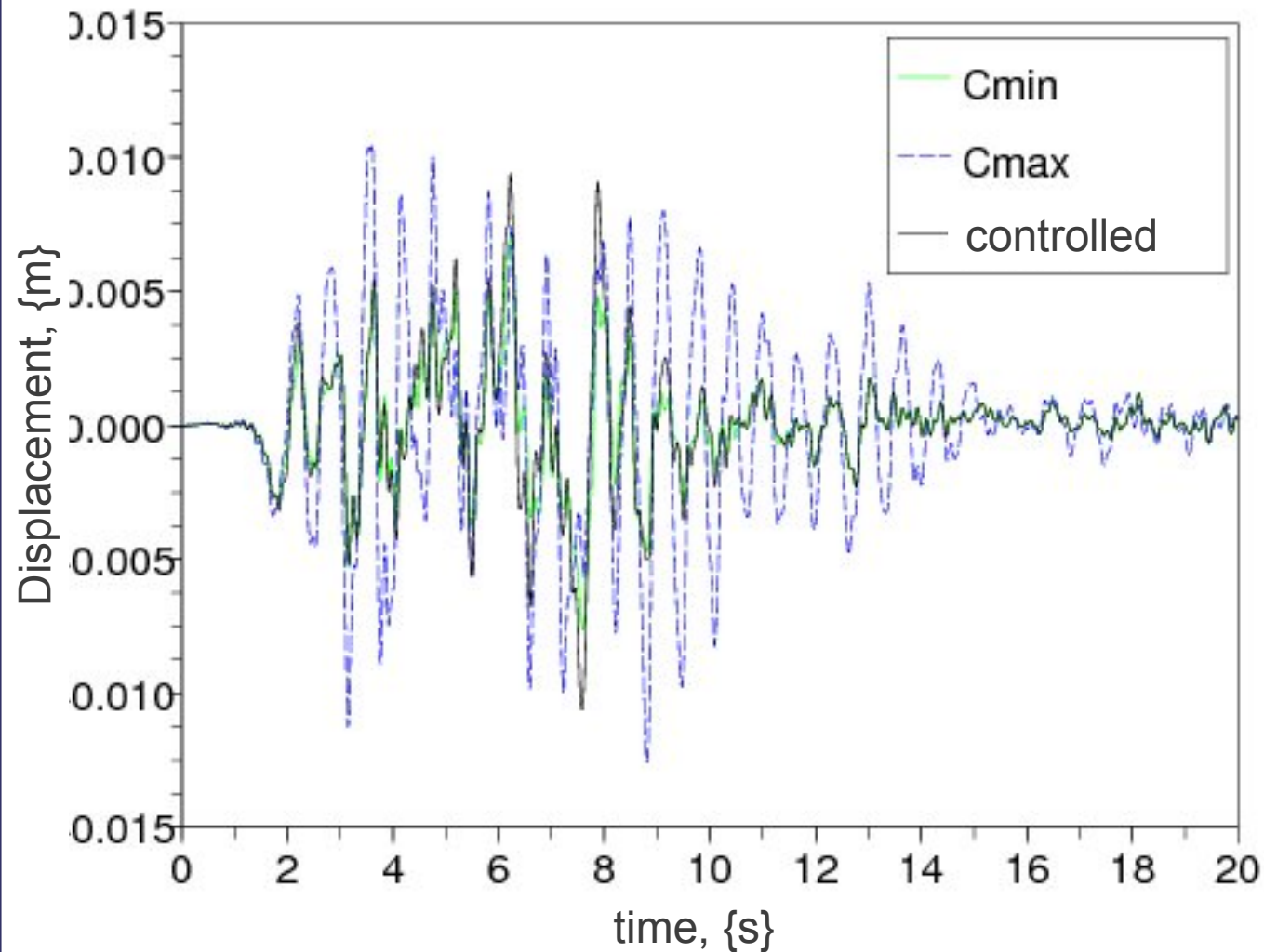


## Base Displacement: 17AguSKR



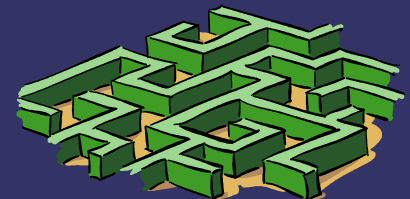
# *Response simulation*

1st story Displacement: 17AguSKR



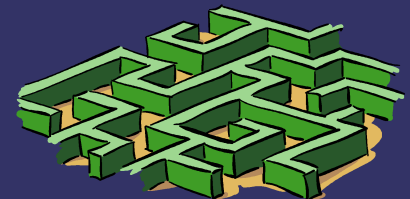
# Response simulation

	d	$C_{\min}$	$C_{\max}$	$C_{\text{contr}}$	$\frac{C_{\text{contr}} - C_{\min}}{C_{\min}}$
El Centro	Base {m}	0.035	0.013	0.022	-35 %
	1st story {m}	0.016	0.033	0.020	26 %
Bolu	Base {m}	0.067	0.016	0.035	-48 %
	1st story {m}	0.022	0.048	0.036	69 %
Sakarya	Base {m}	0.047	0.012	0.023	-50 %
	1st story {m}	0.0076	0.0126	0.0106	39 %



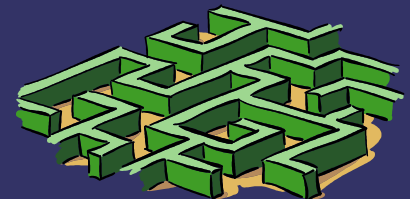
# Response simulation

	d	$C_{\min}$	$C_{\max}$	$C_{\text{contr}}$	$\frac{C_{\text{contr}} - C_{\min}}{C_{\min}}$
El Centro	Base {m}	0.035	0.013	0.022	-35 %
	1st story {m}	0.016	0.033	0.020	26 %
Bolu	Base {m}	0.067	0.016	0.035	-48 %
	1st story {m}	0.022	0.048	0.036	69 %
Sakarya	Base {m}	0.047	0.012	0.023	-50 %
	1st story {m}	0.0076	0.0126	0.0106	39 %



# Response simulation

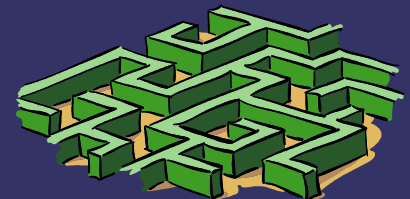
	d	$C_{\min}$	$C_{\max}$	$C_{\text{contr}}$	$\frac{C_{\text{contr}} - C_{\min}}{C_{\min}}$	$\frac{C_{\text{contr}} - C_{\max}}{C_{\max}}$
El Centro	Base {m}	0.035	0.013	0.022	-35 %	69 %
	1st story {m}	0.016	0.033	0.020	26 %	-37 %
Bolu	Base {m}	0.067	0.016	0.035	-48 %	117 %
	1st story {m}	0.022	0.048	0.036	69 %	-24 %
Sakarya	Base {m}	0.047	0.012	0.023	-50 %	90 %
	1st story {m}	0.0076	0.0126	0.0106	39 %	-16 %



# Results

Benefits of using base isolators together with semi active dampers

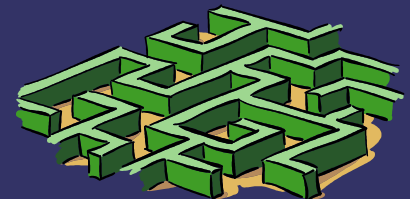
- ➔ Isolator displacement is reduced (%35-%50 reduction w.r.t. min. damping case).
- ➔ No significant increase in 1st story displacement response (%16-%37 w.r.t. max. damping)
- ➔ This control system is robust because energy is only introduced to change the valve positions of the dampers



# Results

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- ➔ Isolator displacement is reduced (%35-%50 reduction w.r.t. min. damping case).
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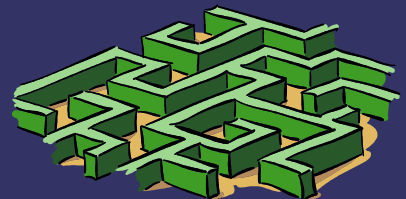




# Results

Benefits of using base isolators together with semi active dampers

- ➔ Isolator displacement is reduced (min. sönümlemeye göre 35-%50 azalmıştır.).
- ➔ No significant increase in 1st story displacement response (%16-%37 w.r.t. max. damping)
- ➔ This control system is robust because energy is only introduced to change the valve positions of the dampers



Thank you

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