



1. YÜKSEK YAPILAR SEMPOZYUMU
04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



YÜKSEK BİNALARDA YAPISAL YANGIN MÜHENDİSLİĞİ

Doç.Dr. Serdar Selamet

Boğaziçi Üniversitesi, İnşaat Mühendisliği Bölümü Öğretim Üyesi



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Alma Mater

2006	Lisans (CEE)	Duke University
2011	Ph.D. (CEE)	Princeton University
2012-	Doç. Dr.	Boğaziçi University
2014	Ziyaretçi Araştırmacı	UC Berkeley
2016-17	Ziyaretçi Araştırmacı	U. of Manchester (U.K.)

- ❑ Editorial Board: Fire Safety Journal
- ❑ Society of Fire Protection Engineering (SFPE) Üyesi
- ❑ ASCE Fire Engineering Teknik Komite Üyesi
- ❑ Türkiye’de ilk ve tek «Yangın Mühendisliği» ders kitabı.
(2022, 282 sayfa, Nobel Akademik Yayıncılık,
ISBN: 9786254179655, )

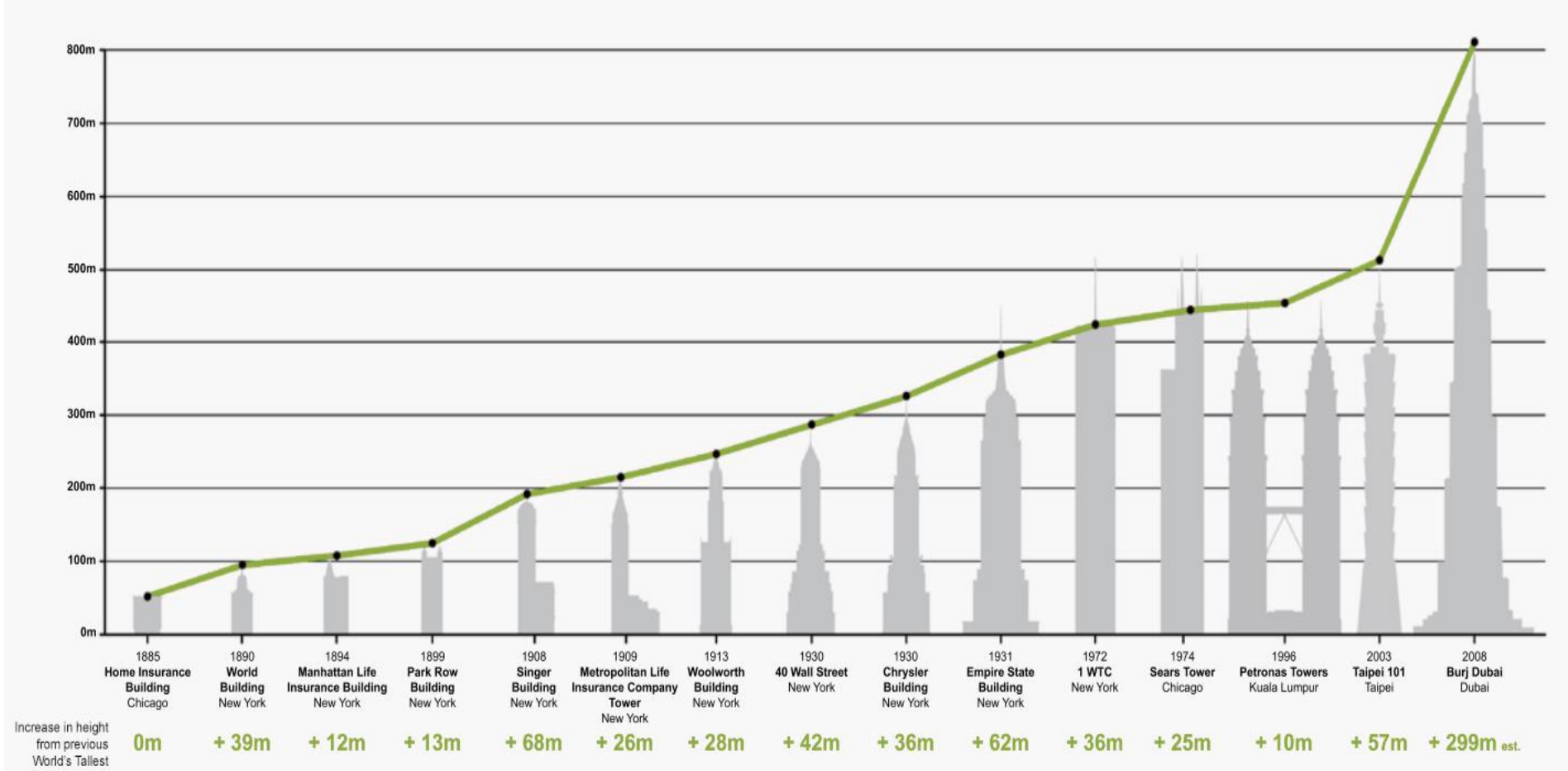




1. YÜKSEK YAPILAR SEMPOZYUMU

04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Bina yükseklik artışı



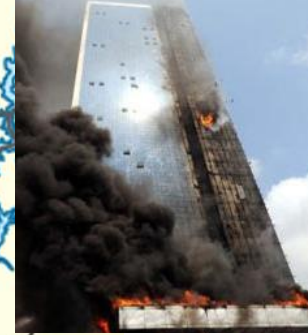
1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



42 yangın istasyonu

1200 çok katlı konut



Istanbul 2012



Caracas
2004



Windsor 2005



Beijing 2009



Philadelphia
1991



Jakarta 2015



Dubai 2015



London 2017

Bina yangını olasılığı : $2.4 \times 10^{-7} / \text{m}^2 / \text{yıl}$

5000 m² alan: % 0.12 / yıl

Lange et al. 2014



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI

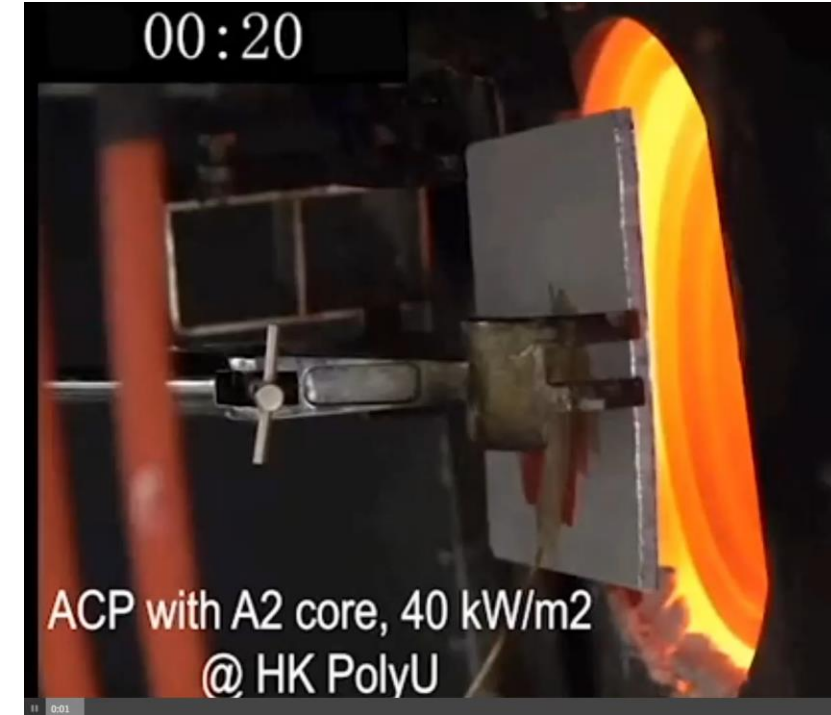
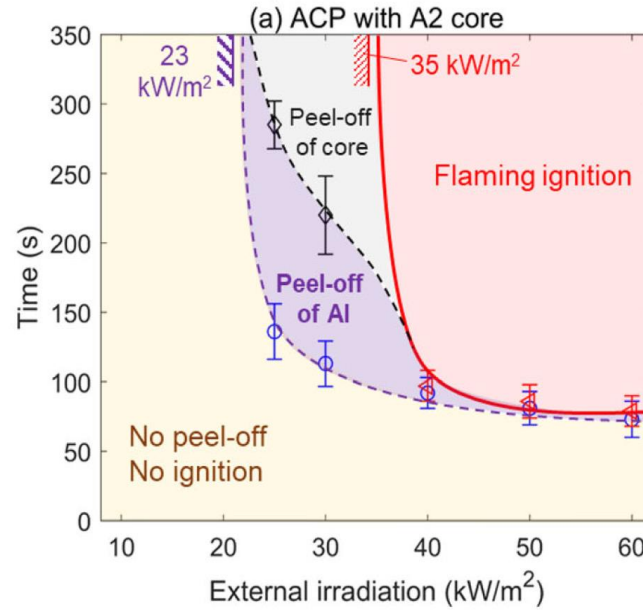


✓ Façade yangınları

Problem: Kompozit malzeme (Aluminyum+PIR panel)



Grenfell Tower yangını, 2017



Kaynak: Khan et al. 2023 (Fire Technology)



1. YÜKSEK YAPILAR SEMPOZYUMU

04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



2.47am 'Stay put' advice officially revoked

2.00 am Flames start to spread around the crown of the tower and diagonally across the rest of the building

1.27 am Fire reaches the roof and starts to spread horizontally

1.30 am Marien Elgahry call 999 to report fire in flat 196 on floor 22

1.25 am Denis Murphy calls 999 to report smoke entering flat on floor 14

1.09 am Fire breaks out of flat 16 into exterior cladding and starts to climb the tower

12.54 am Behailu Kebede calls 999 to report fire in flat 16, floor 4

Graphic after Official Inquiry Phase One Report

72 kişi hayatını kaybetmiştir.

En yüksek 3 kattaki hiç kimse kurtulamamıştır.

Yangınlarda ölümlerin yaklaşık %50'si duman zehirlenmesi ile olmaktadır,

Yangın, tüm dış cepheyi **15 dakika** içinde sarmıştır.

Yangın **30 dakika** içinde kontrolden çıkmıştır.

Dış cephe malzemesinde (PIR-polyisocyanurate) zor alevlenici malzeme kullanıldığı (B-tipi) tespit edilmiştir.

'Yerinde kal' tahliye stratejisi ölümlere sebep olmuştur.

Duman, çoğunlukla yangının ilk habercisidir...

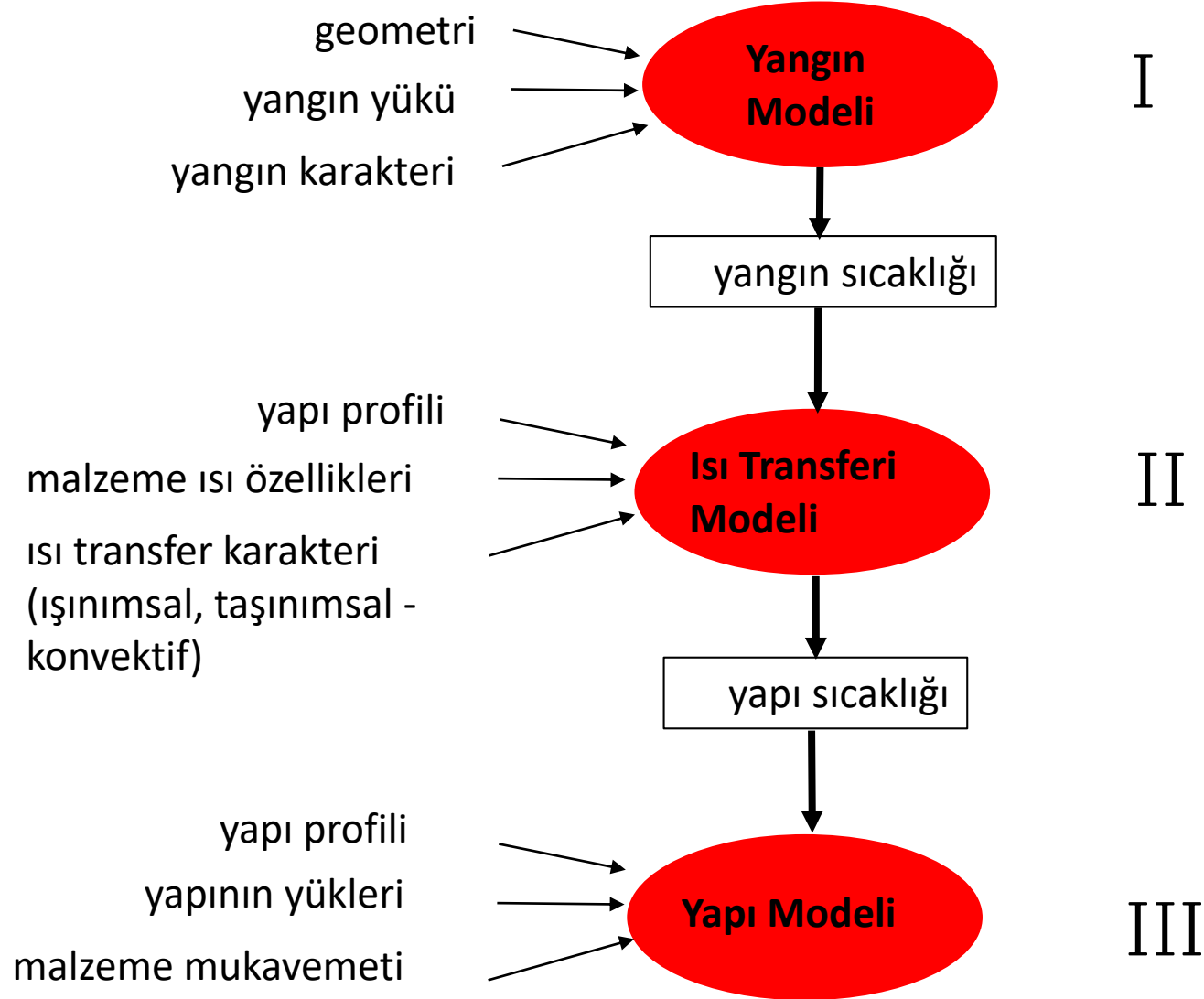
24 Kat	+	(1)
23 Kat	+++++	(6)
22 Kat	+++++	(10)
21 Kat	+++++	(14)
20 Kat	+++	(3)
19 Kat	+++++	(8)
18 Kat	+++++	(14)
17 Kat	+++	(4)
16 Kat		
15 Kat		
14 Kat	+	(1)
13 Kat		
12 Kat		
5 Kat	MGM Grand	
4 Kat	21 Kasım 1980	
3 Kat		
2 Kat		
1 Kat	+++++	(18)

Toplamda 85 ölüm



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI





I

YANGIN

$$\frac{\partial u}{\partial t} + (u \cdot \nabla) u = -\nabla p + \nu \nabla^2 u$$

Navier-Stokes Denklemi





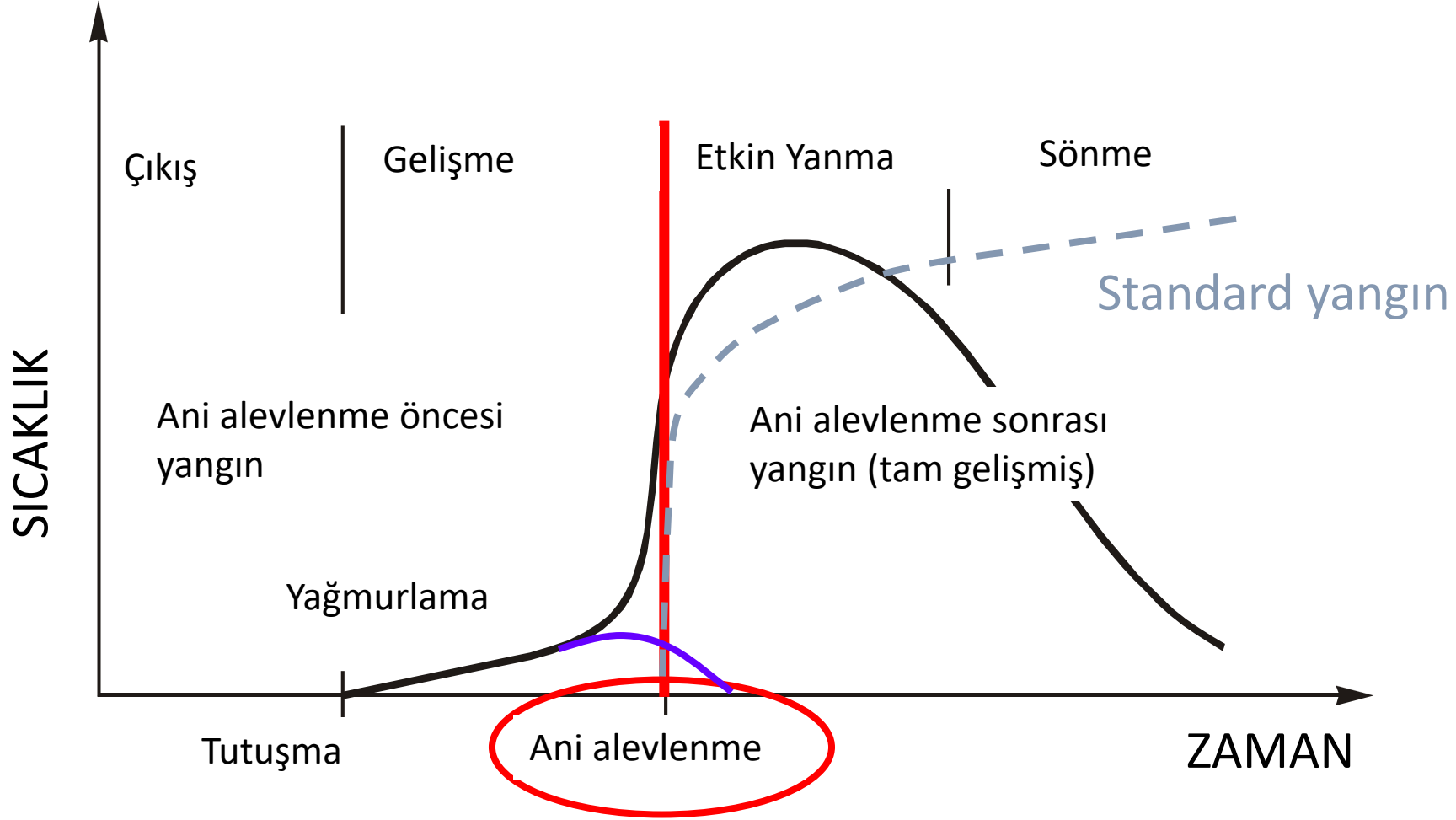
1. YÜKSEK YAPILAR SEMPOZYUMU

04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI

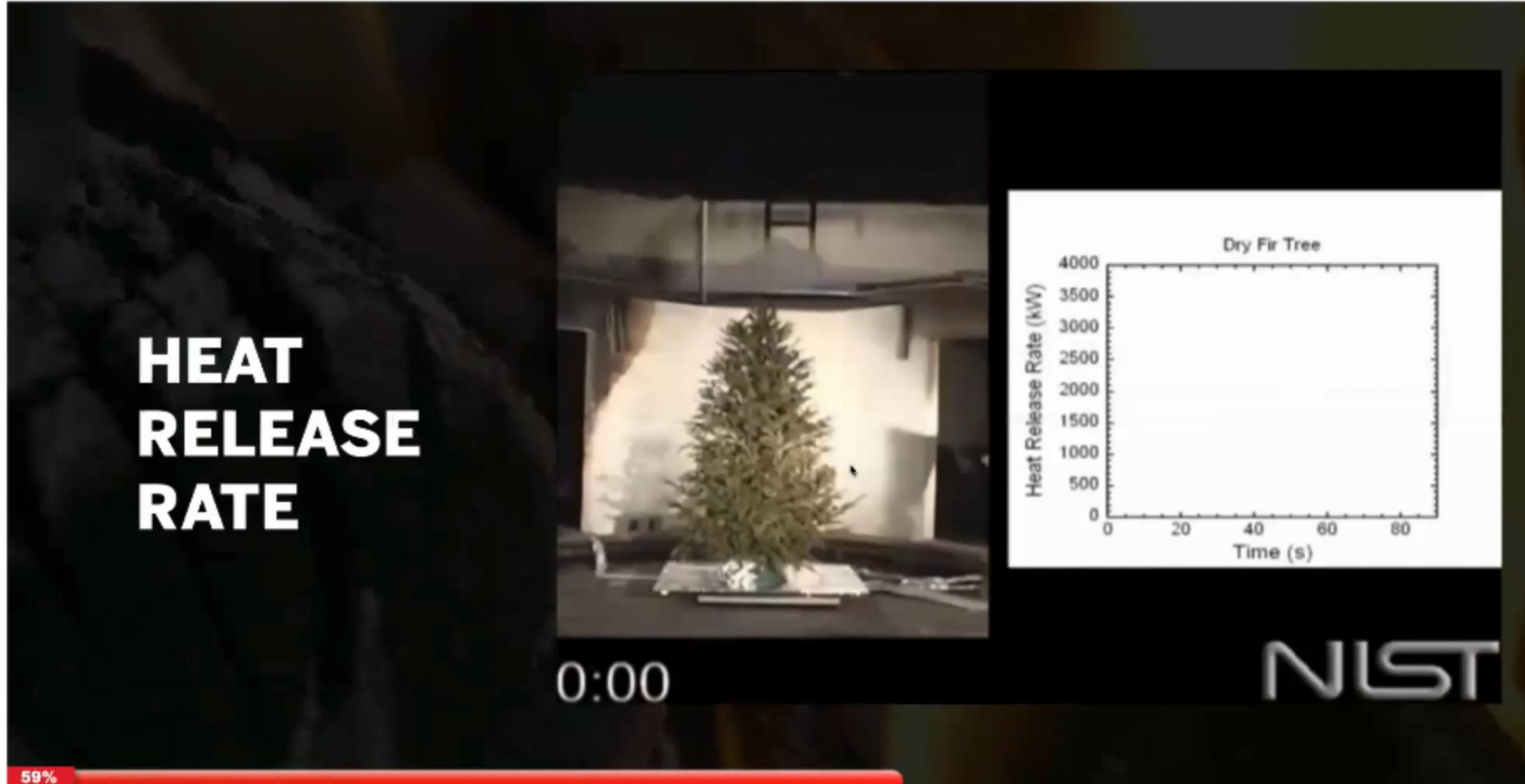


Ani alevlenme: Tüm yanıcı maddelerin ateşten uzak olsa dahi sıcak gazlardan dolayı tutuşması
 $T \geq 600\text{ }^{\circ}\text{C}$ ya da $h_{rad} = 20\text{ kJ/m}^2$

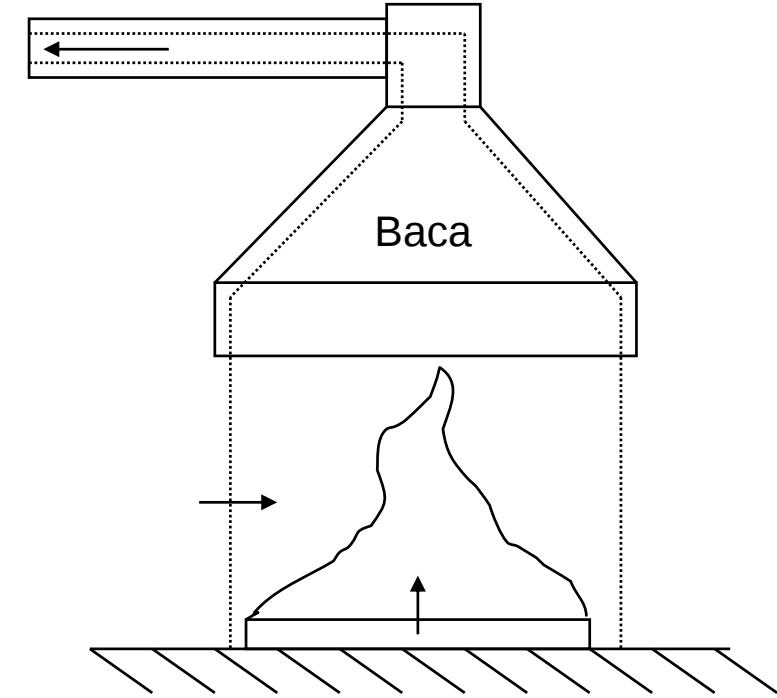




ISI SALINIM HIZI



KALORİMETRE





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI

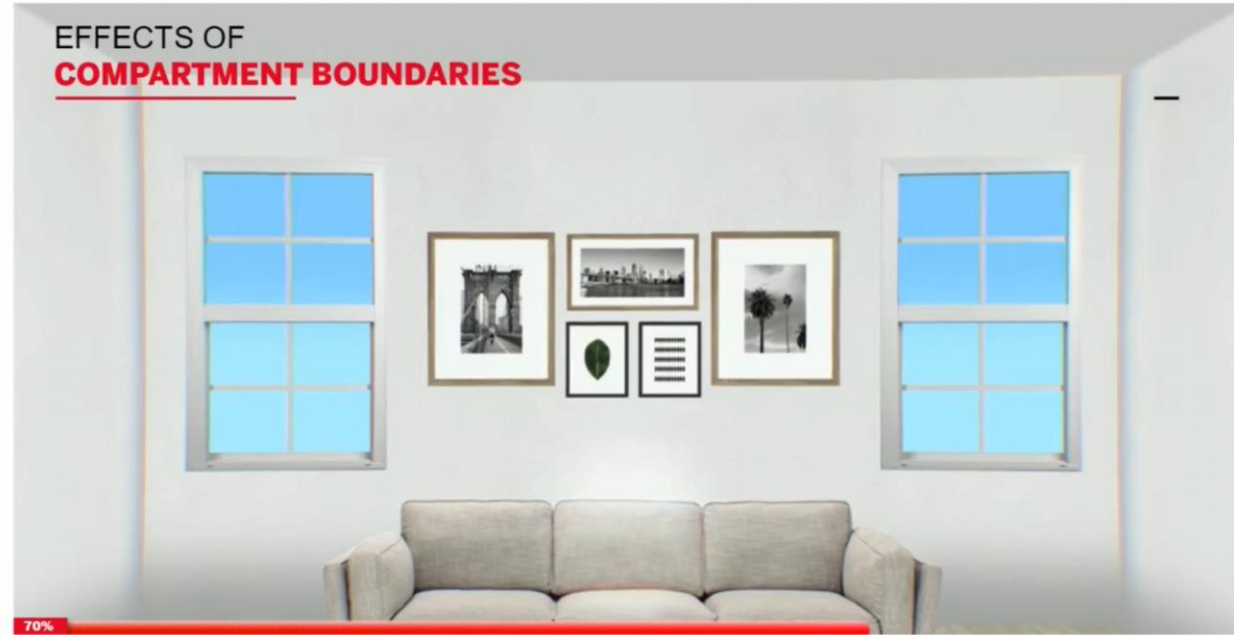
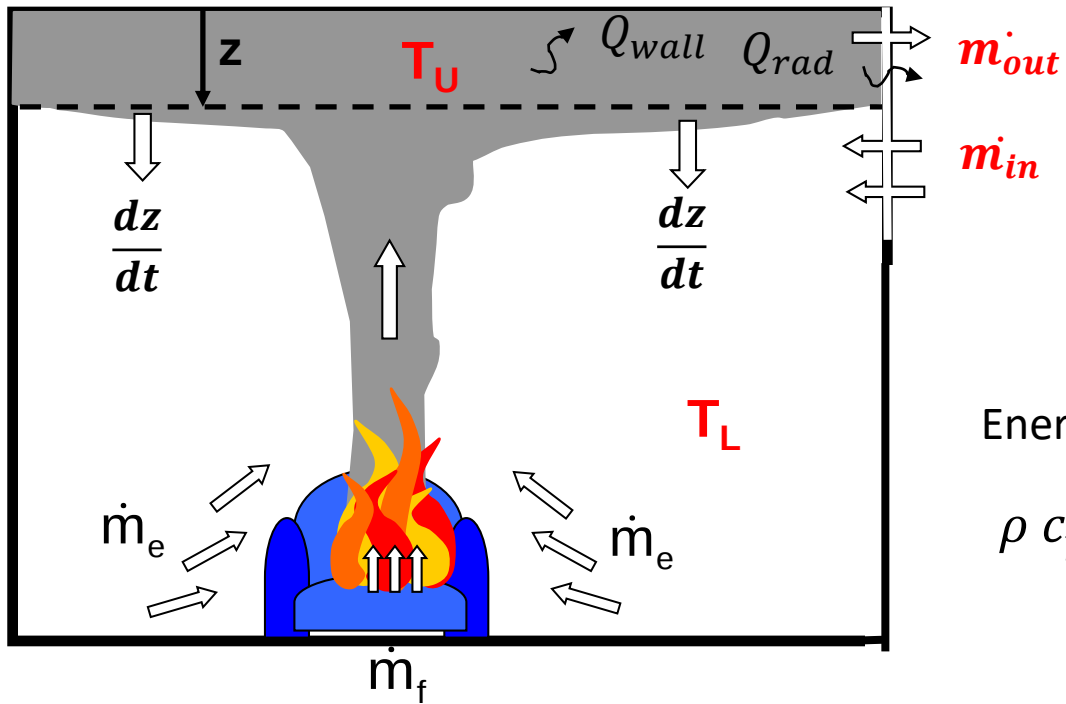


$$Q_f = \dot{m}_f \Delta H_c$$

Kütle Denklemi

$$A \frac{d}{dt}(\rho z) + \underbrace{\sum_{j=1}^J \dot{m}_j}_{\text{Net out}} = 0$$

$$\sum_{j=1}^J \dot{m}_j = \dot{m}_{out} - \dot{m}_{in} - \dot{m}_e - \dot{m}_f$$



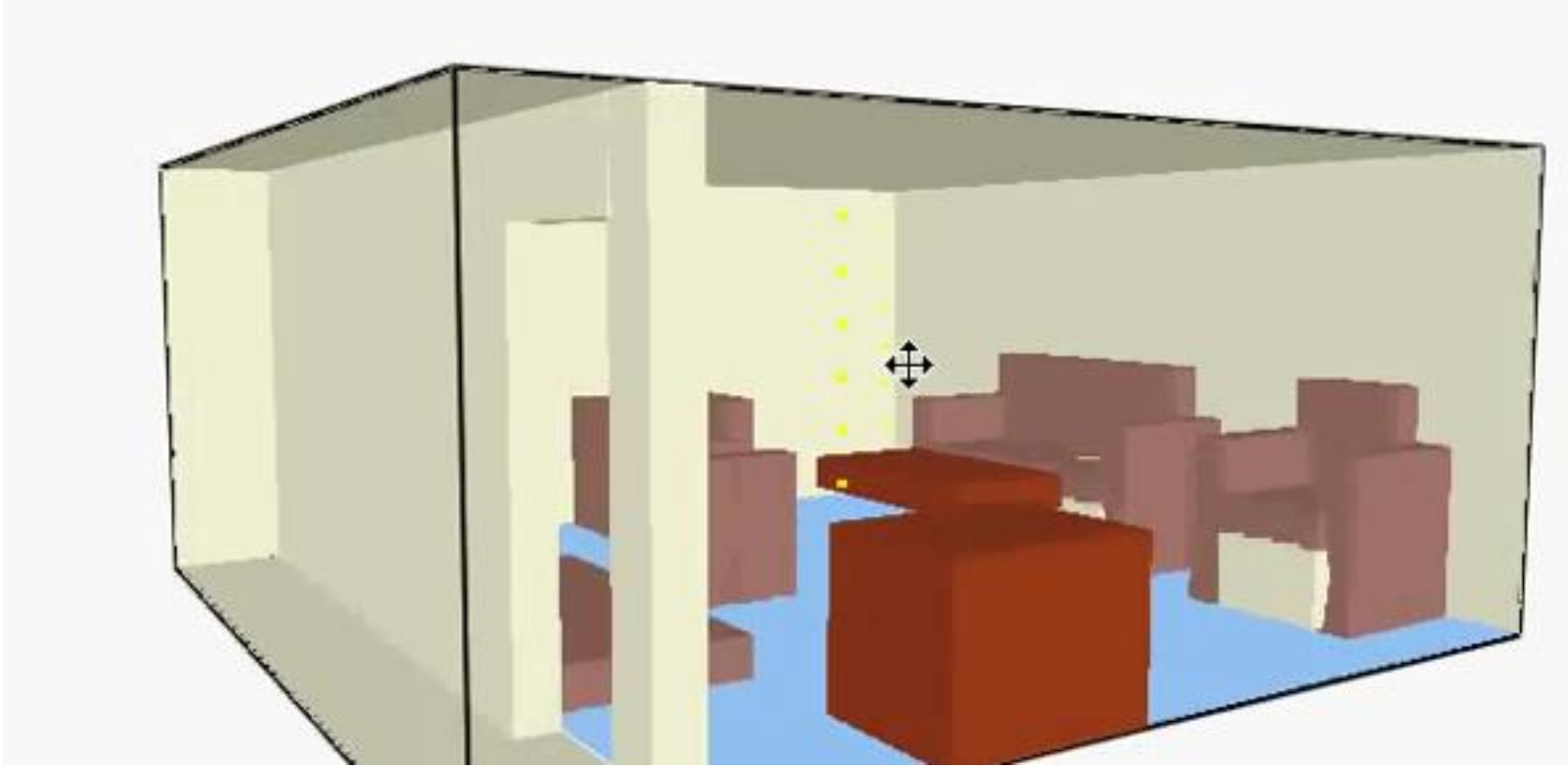
Enerji Denklemi

$$\rho c_p z A \frac{dT}{dt} - z A \frac{dp}{dt} + c_p \sum_{j=1}^J \dot{m}_j (T_j - T) = Q_f - Q_{wall} - Q_{rad}$$



1. YÜKSEK YAPILAR SEMPOZYUMU
04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



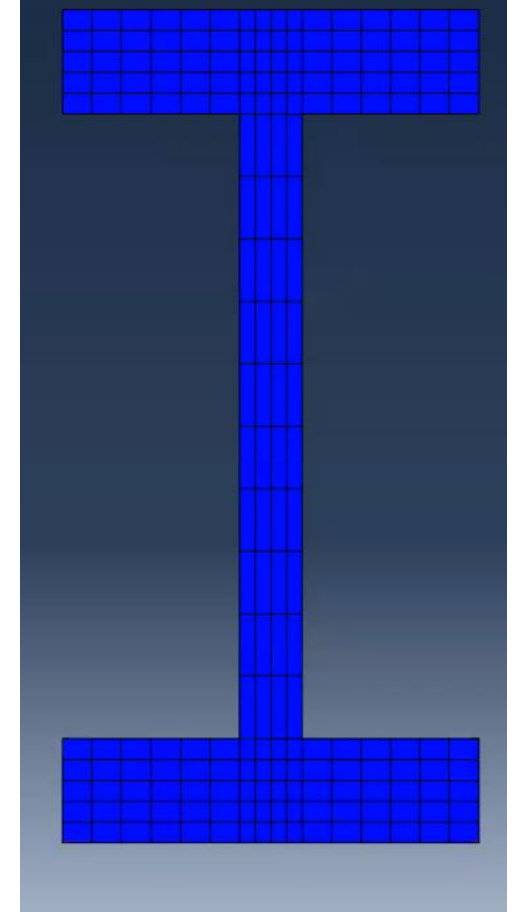
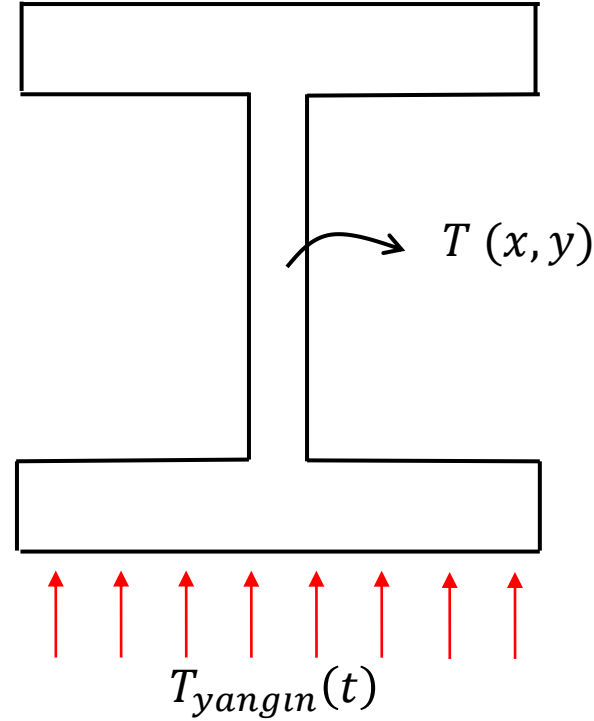


II

ISI TRANSFERİ

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \rho c / k \frac{dT}{dt} + S$$

Poisson Denklemi



Kaynak: FEHEAT sonlu eleman programı,
Boğaziçi Üniversitesi



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



İletkenlik: $q_x = -k \left(\frac{\partial T}{\partial x} \right)$

Konveksiyon: $q_x = h(T - T_\infty)$

Işınım: $q_x = \phi \varepsilon \sigma (T^4 - T_\infty^4)$



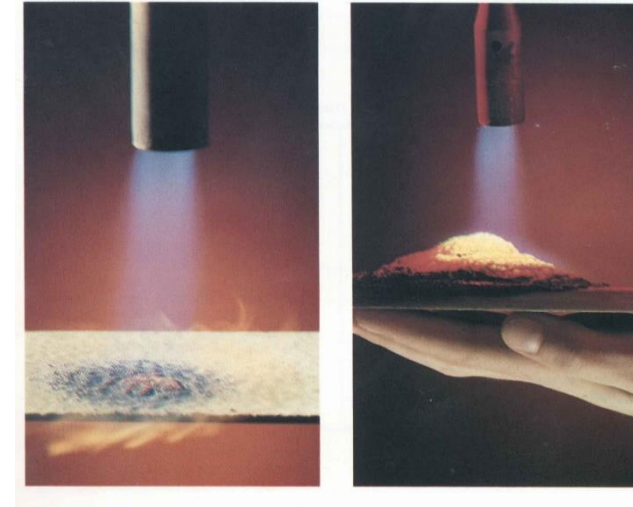
Sıcaklık artışı

Korunmasız çelik

$$\Delta T_s = F/V \frac{1}{\rho_s c_s} \{h(T_{fire} - T_s) + \sigma \varepsilon (T_{fire}^4 - T_s^4)\} \Delta t$$

Yalıtımlı çelik

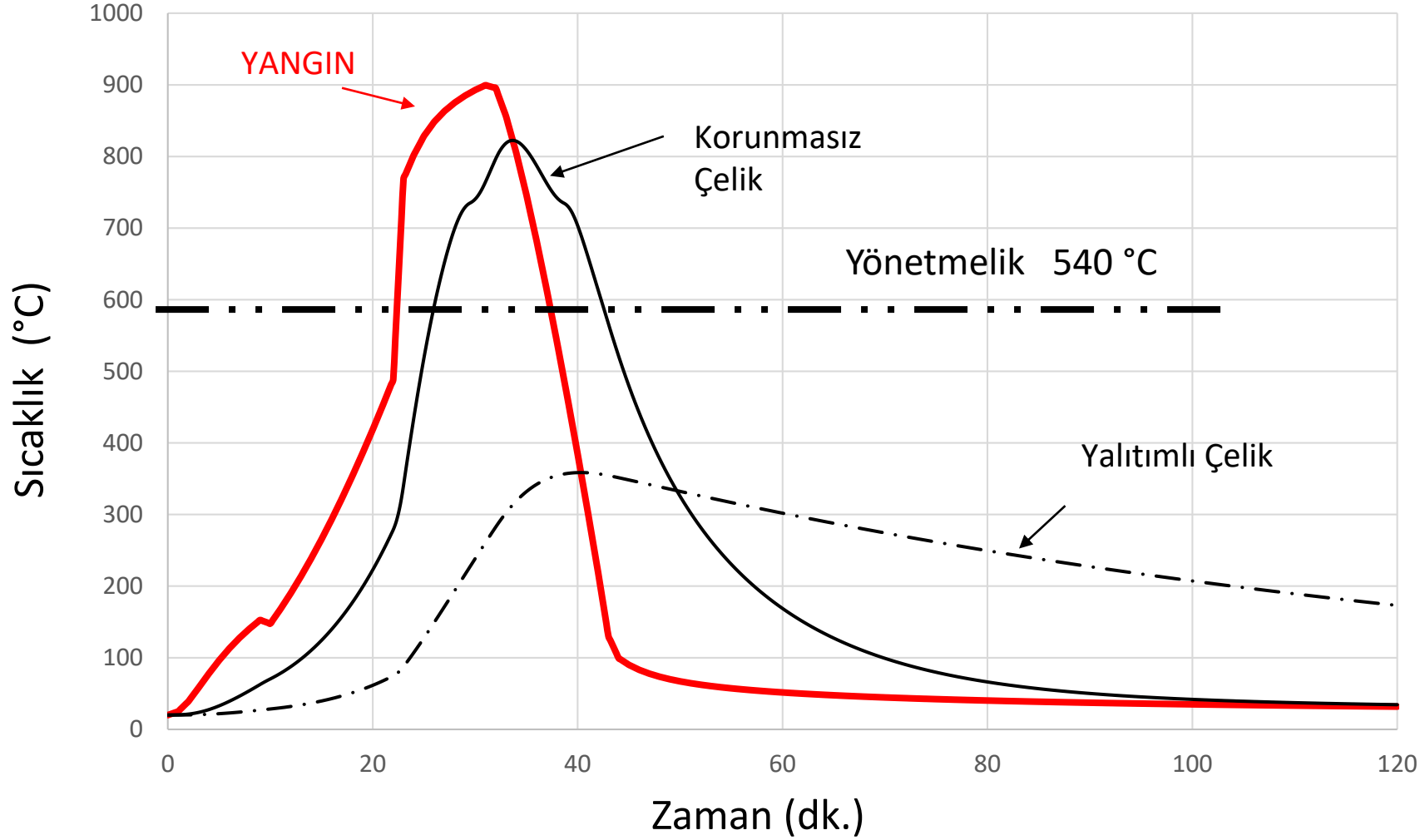
$$\Delta T_s = F/V \frac{k_i/d_i}{\rho_s c_s} \frac{T_{fire} - T_s}{1 + \phi/3} \Delta t - \left(e^{\frac{\phi}{10}} - 1 \right) \Delta T_{fire} \quad \phi = F/V \frac{c_i \rho_i d_i}{c_s \rho_s}$$





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI





III

YAPISAL YANGIN PERFORMANSI

$$[K] \begin{Bmatrix} u_M \\ u_T \end{Bmatrix} = f$$

Termo-mekanik yapı davranış analizi





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Çok katlı konutlarda yangın yükü ve yayılımı

Fire Safety Journal 135 (2023) 103710

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf



Fire load and fire growth characteristics in modern high-rise buildings

Ugur Dundar^a, Serdar Selamet^{b,*}

^a Dept. of Civil Engineering, Bogazici University, Istanbul, Turkey

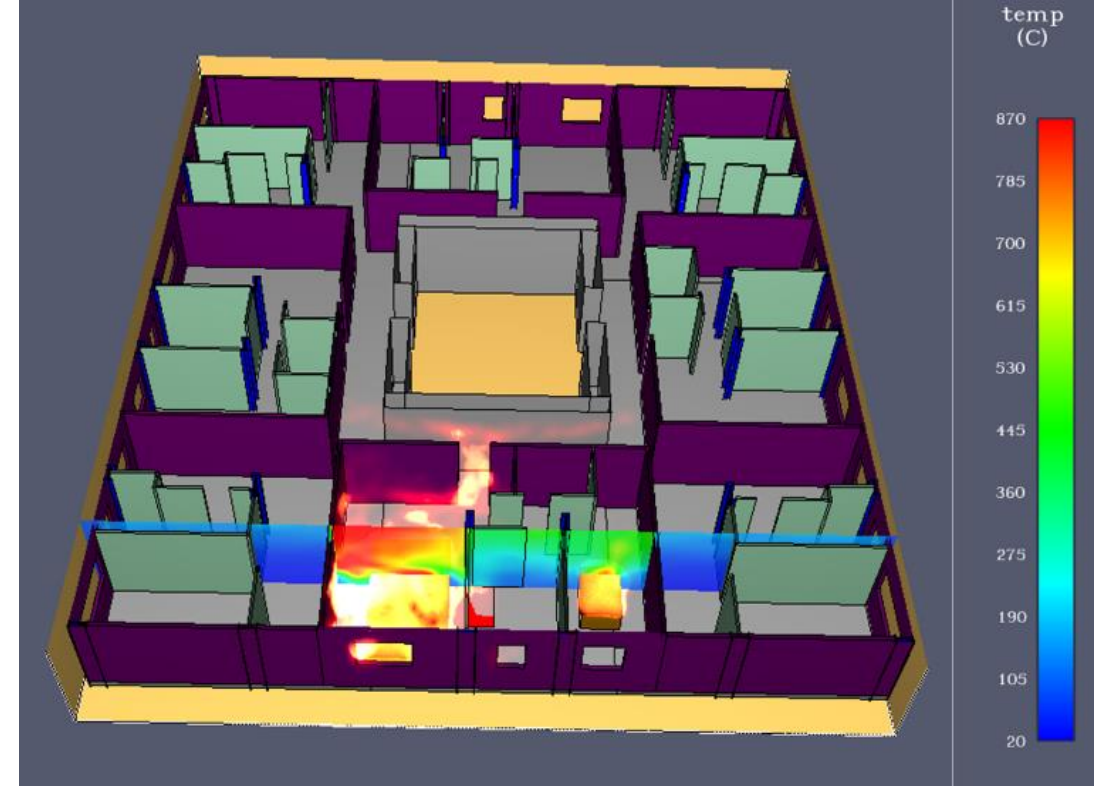
^b Dept. of Civil Engineering, Bogazici University, Bebek, Istanbul, 34342, Turkey

ARTICLE INFO

Keywords:
Fire load
Residential
Heat release rate
Dwelling
Survey
FDS

ABSTRACT

Fire load is the major contributor to the heat release rate, which defines the severity of a fire event in buildings. It is necessary to have a well-defined fire load for residential buildings to perform an adequate fire safety design. This study estimates the fire load and fire growth for modern residential apartments using survey results of 50 high-rise buildings in Istanbul, Turkey. The survey methodology is the inventory method primarily based on size measurements and photographic information obtained from physical visits to apartments and digital inventory of real-estate websites. Fire loads in living rooms, bedrooms, and kitchens form the basis of the study. Results show that the average fire load density in living rooms range from 310 MJ/m² to 379 MJ/m² whereas the range is within 518 MJ/m² and 650 MJ/m² for bedrooms. The kitchen has the average fire load density of 552 MJ/m². Eurocode estimation of the fire load density for dwellings is found overly conservative compared to the survey results. The FDS results provide fire spread times of 1 min–11 min depending on the compartment. Cumulative fire growth curves for living rooms, bedrooms and kitchens are generated using fire load surveys and fire spread results.



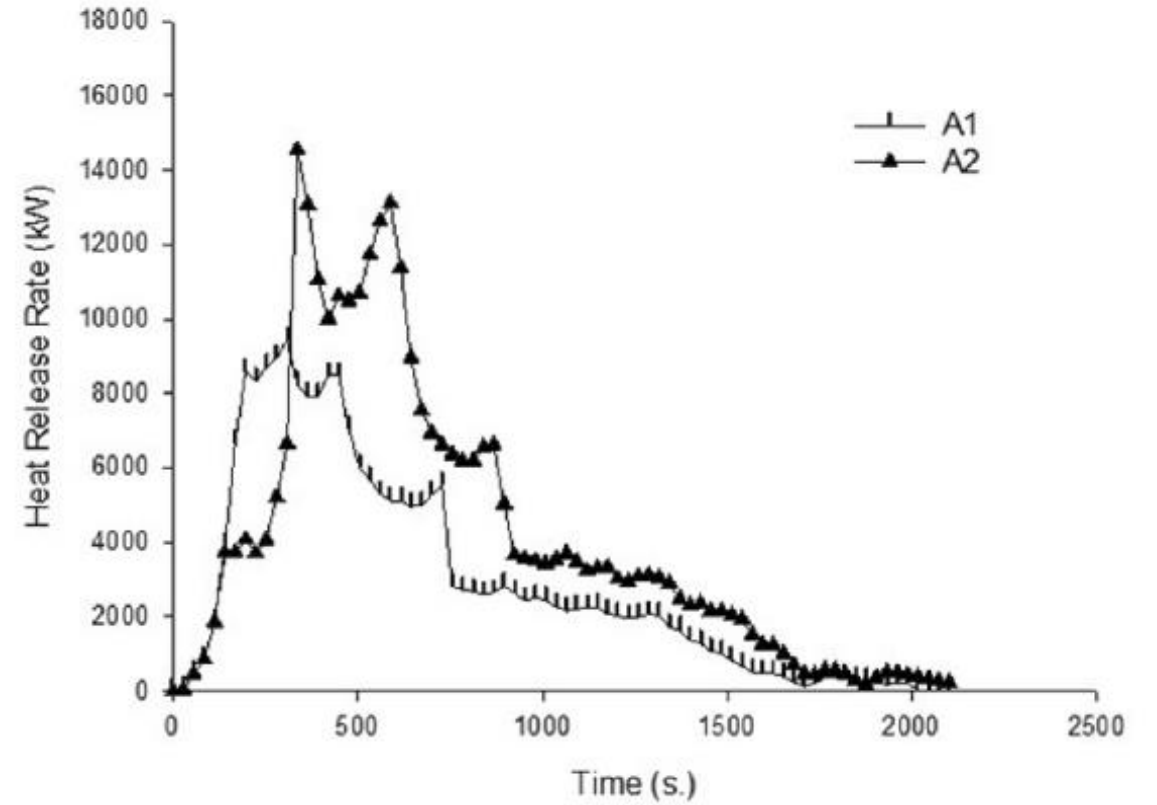
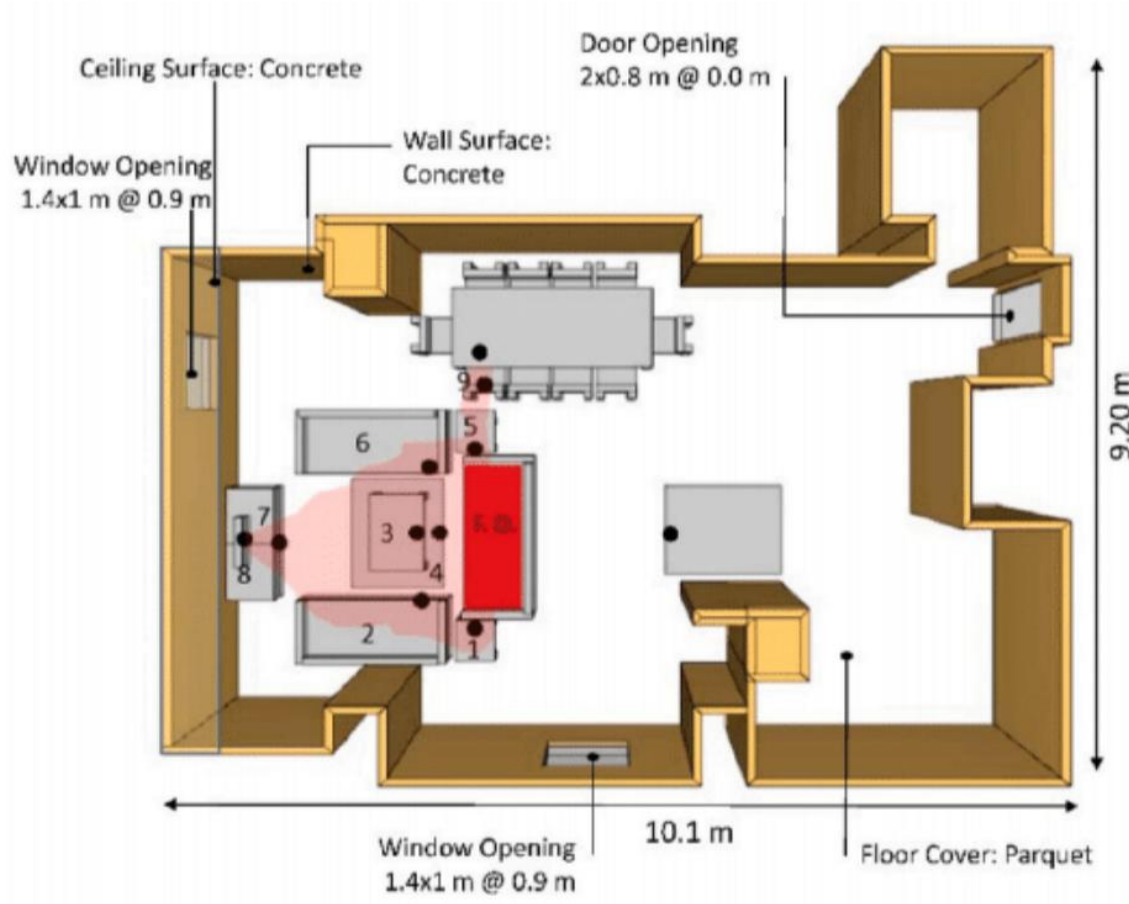


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Çok katlı konutlarda yangın yükü ve yayılımı





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Fire Technology
© 2022 The Author(s), under exclusive license to Springer Science+Business Media, LLC, part of Springer Nature
Manufactured in The United States
<https://doi.org/10.1007/s10694-022-01344-w>



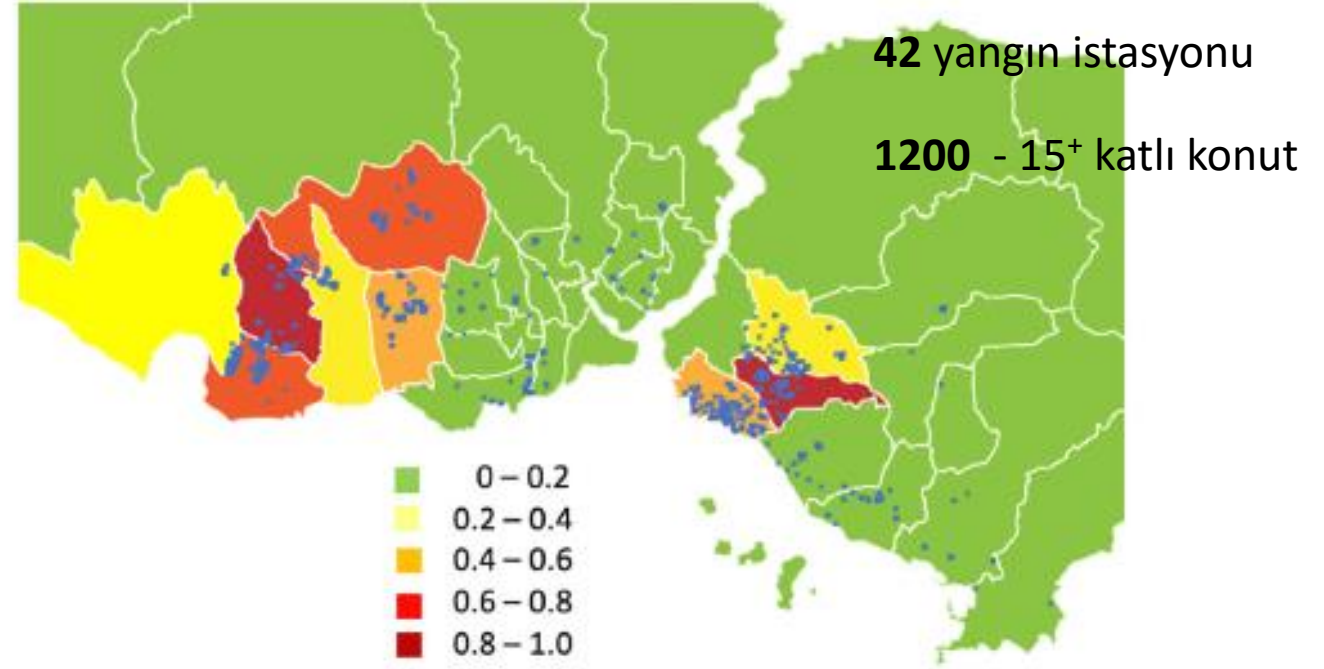
City-Wide Fire Vulnerability Map of High-Rise Residential Buildings

Mustapha M. Jodi and Serdar Selamet *, Department of Civil Engineering,
Bogazici University, Bebek, 34342 Istanbul, Turkey
Yong C. Wang , School of Mechanical, Aerospace and Civil Engineering, The
University of Manchester, Manchester M139PL, UK

Received: 26 January 2022/Accepted: 8 November 2022

Abstract. One of the significant hazards in the event of a fire in high-rise residential buildings in cities is the length of time taken to completely evacuate a large number of occupants. On a city scale, it is important that a city's fire and rescue services are in place to minimize the consequences which can be incurred in any potential fire incident. The paper presents the methodology and results of a study that evaluates the city-wide vulnerability in high-rise residential building fires in the City of Istanbul, Turkey. In the context of fire and rescue service arrival to burning buildings, a high-rise building can be considered vulnerable if the fire and rescue service arrives at the building site only after the expected completion of evacuation of the building, thus unable to fulfill its intended purpose of saving the occupants. The study is based on comparison of an agent-based evacuation model of safe escape times for 1167 high-rise residential buildings against their fire and rescue service arrival times estimated using GPS data. This methodology can be used to inform the decision about optimal locations of a city's fire and rescue services. As an example, this study indicates that adding a single new fire station in the City of Istanbul can improve its preparedness for fire accidents by reducing the risk of its most vulnerable district by more than 26%.

Keywords: High-rise, Evacuation, Firefighting, Vulnerability, Risk map, Fire safety



Yangın çıkma olasılığı: 2.4×10^{-7} / m² / yıl

Lange et al. 2014

5000 m² kat alanı: % 0.12 / yıl

- ☐ FDS analizleri
- ☐ RSET (i.e. tahliye) vs. itfaiye ulaşım süresi
- ☐ Risk indeksi: Yoğun trafikte, binaların %65'i, trafiksiz ortamda binaların %15'i yüksek riskli bulunmuştur.

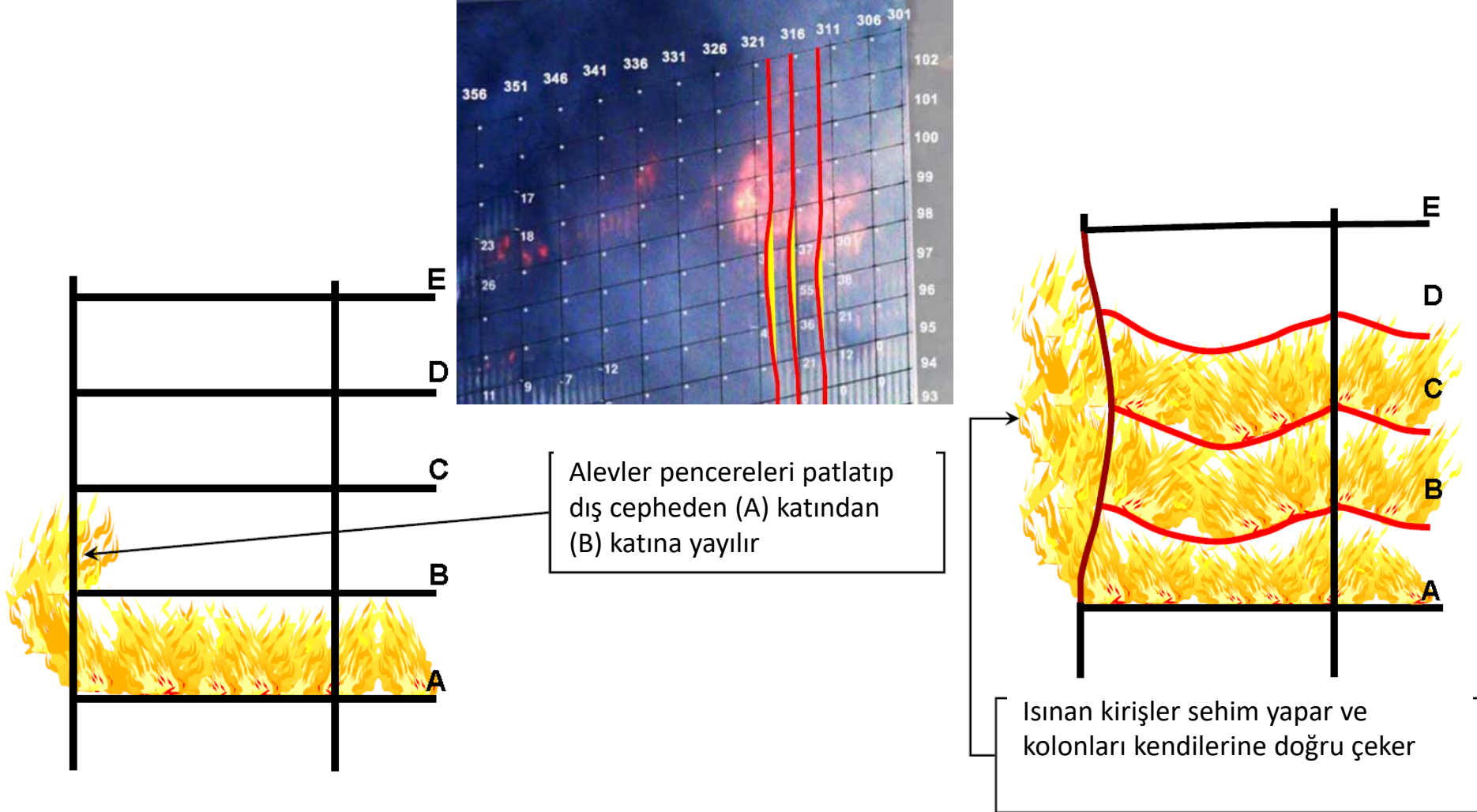


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



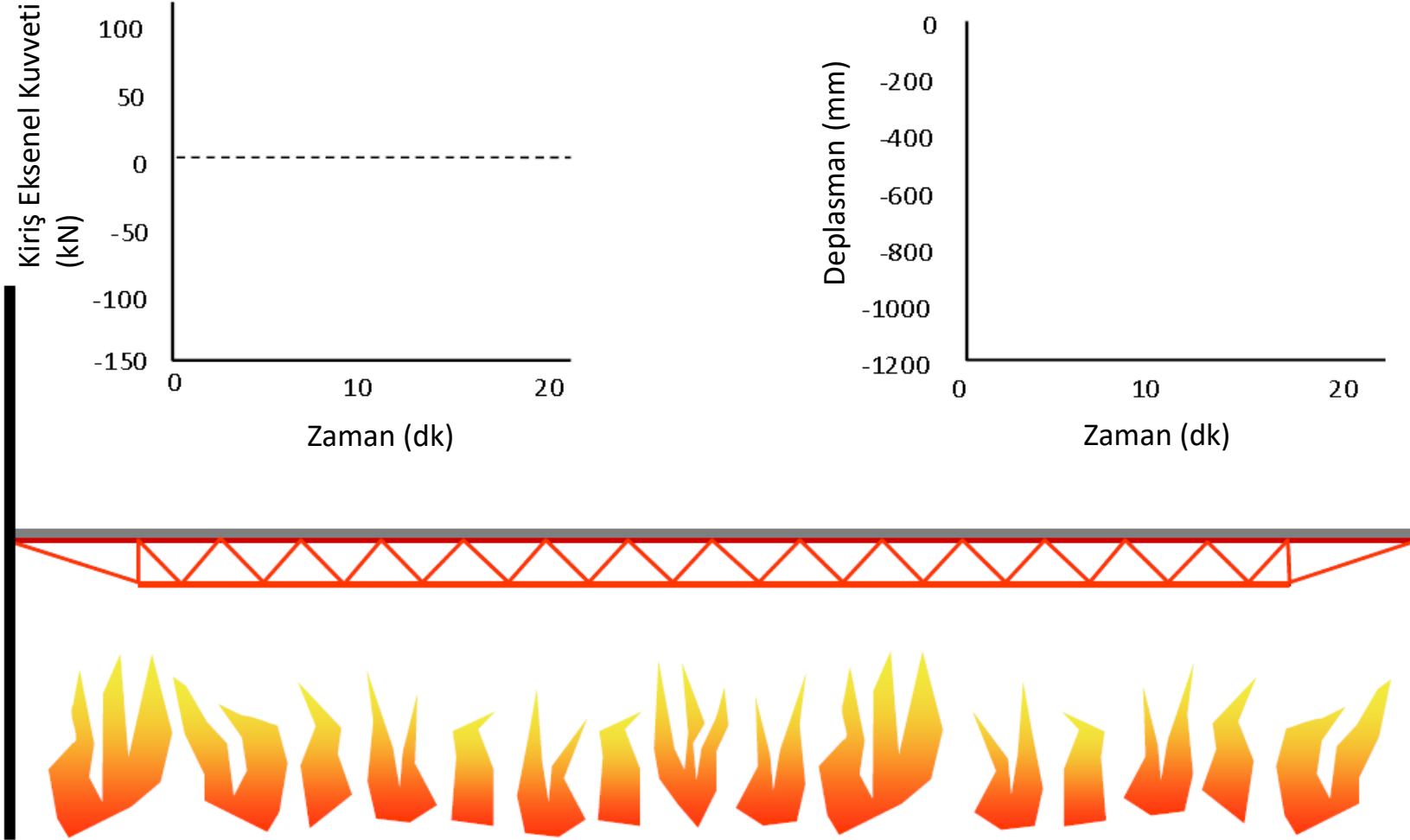
WTC 1: kolonların içeri çekilmesi





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

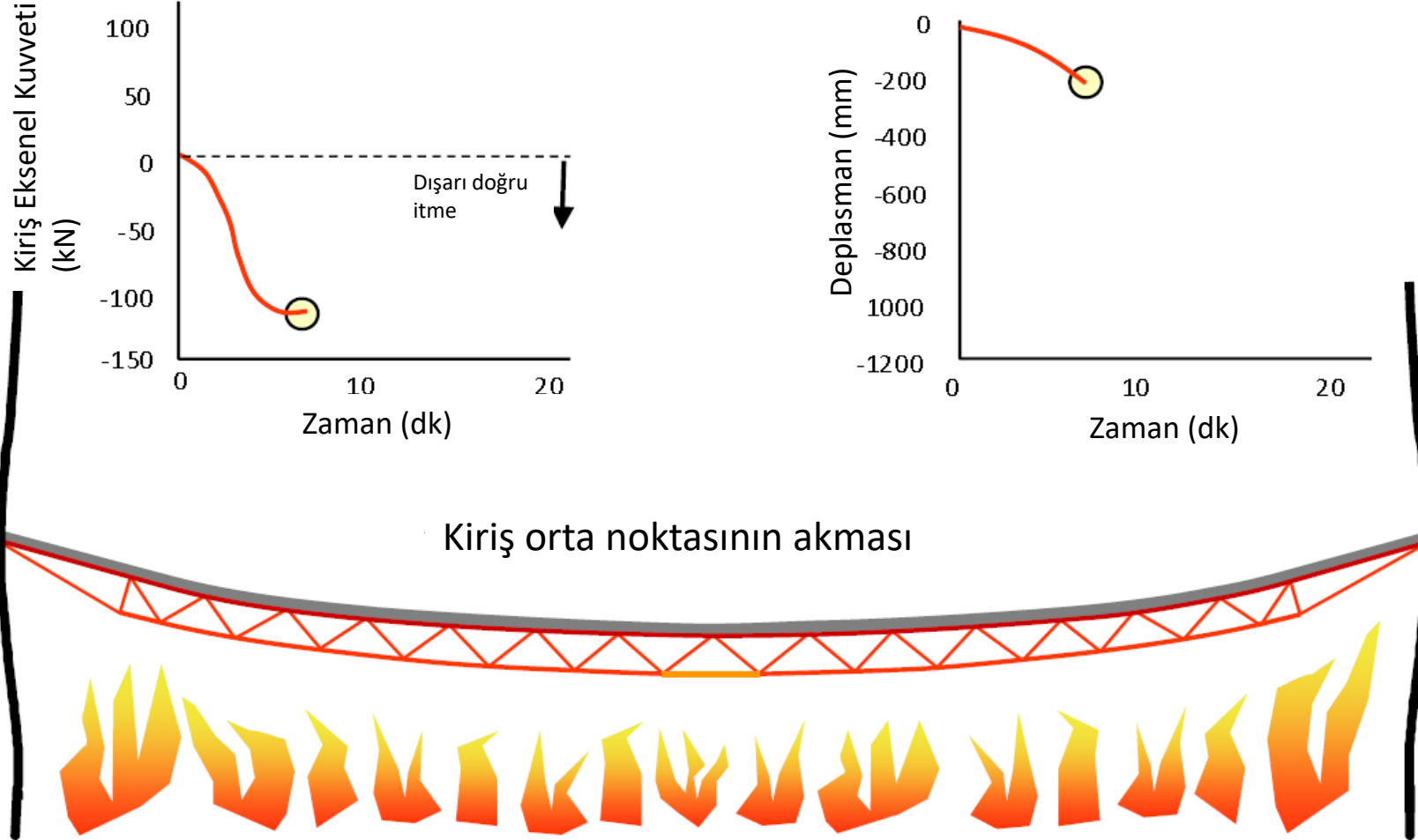
TMMOB
İNŞAAT MÜHENDİSLERİ ODASI





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

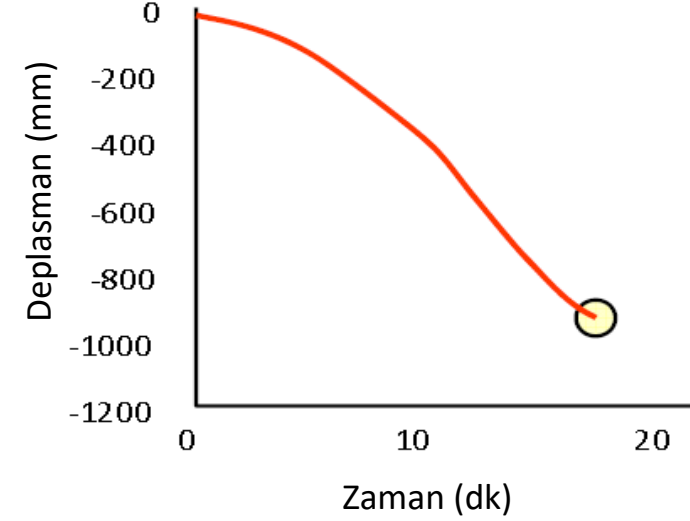
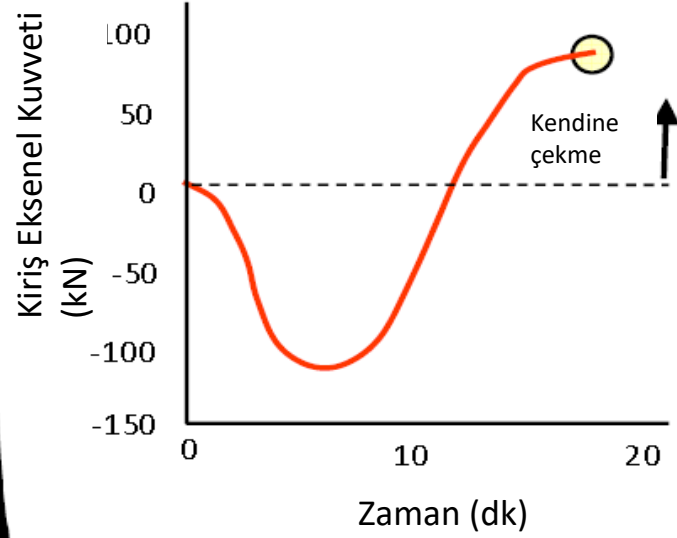
TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



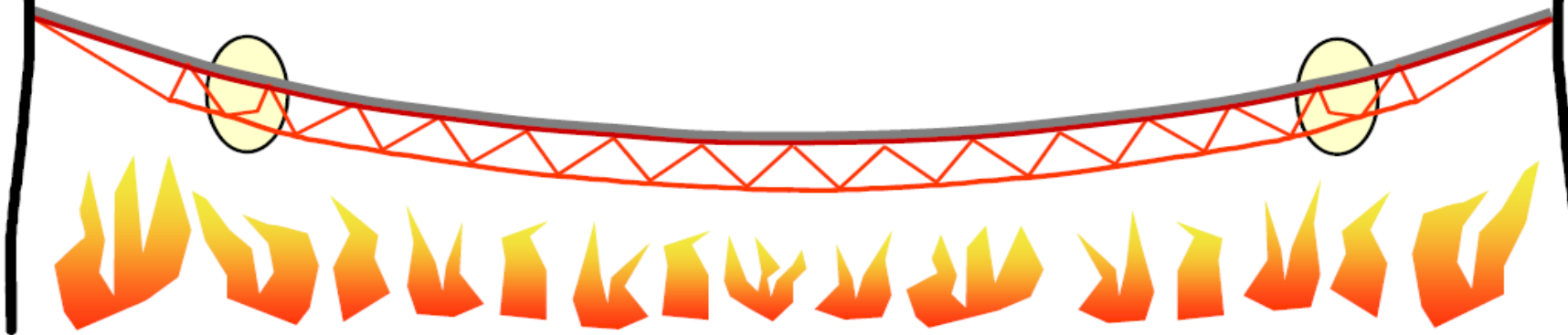


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Diyagonal çaprazların burkulması

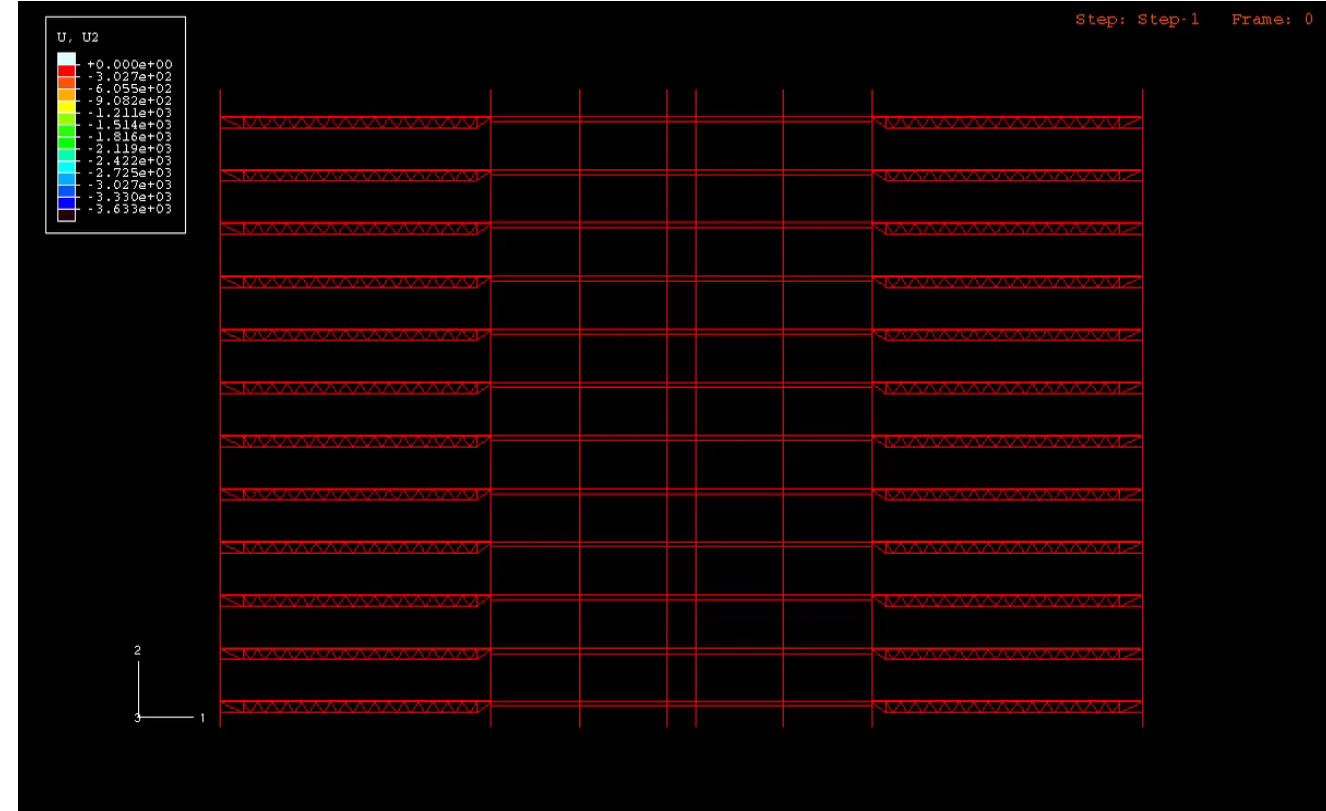
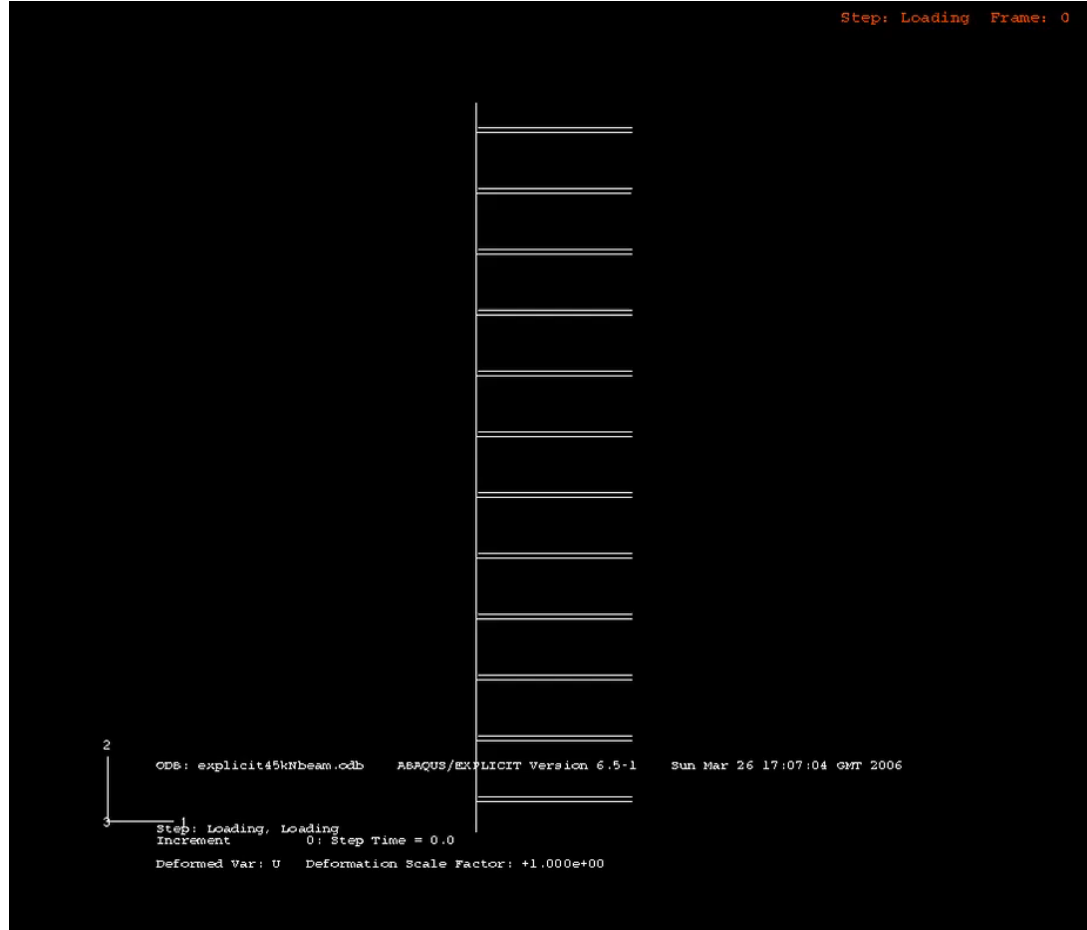




1. YÜKSEK YAPILAR SEMPOZYUMU

04 – 05 MAYIS 2023 İSTANBUL

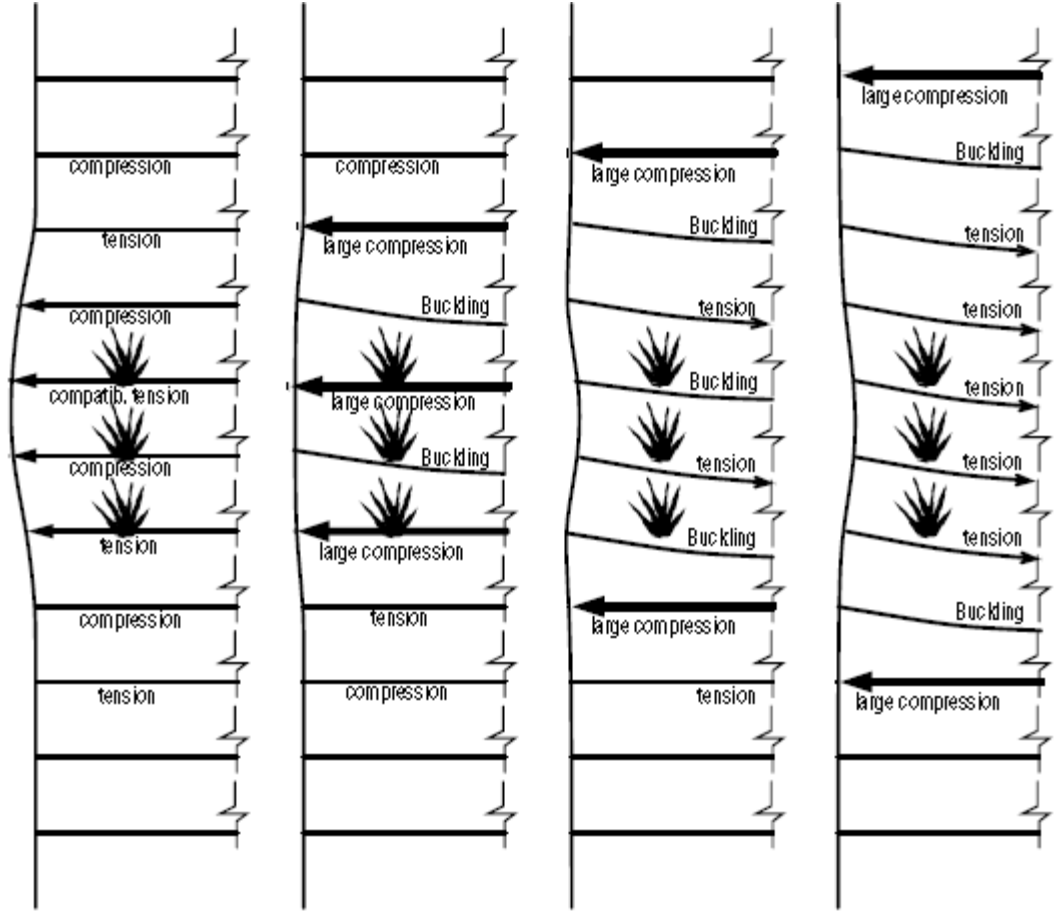
TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



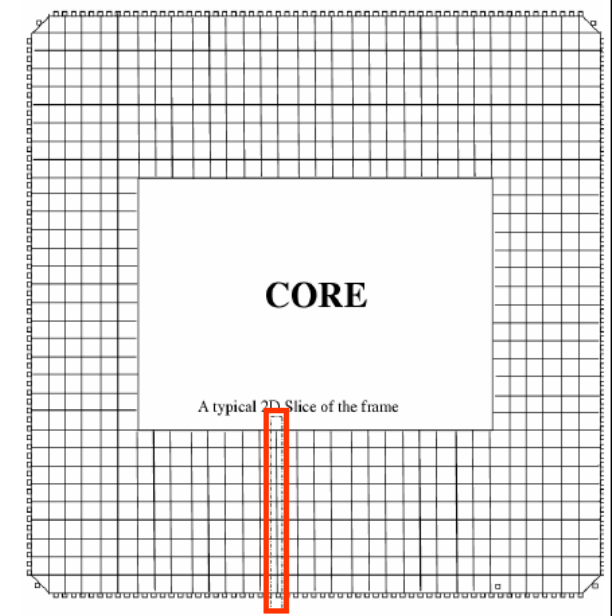
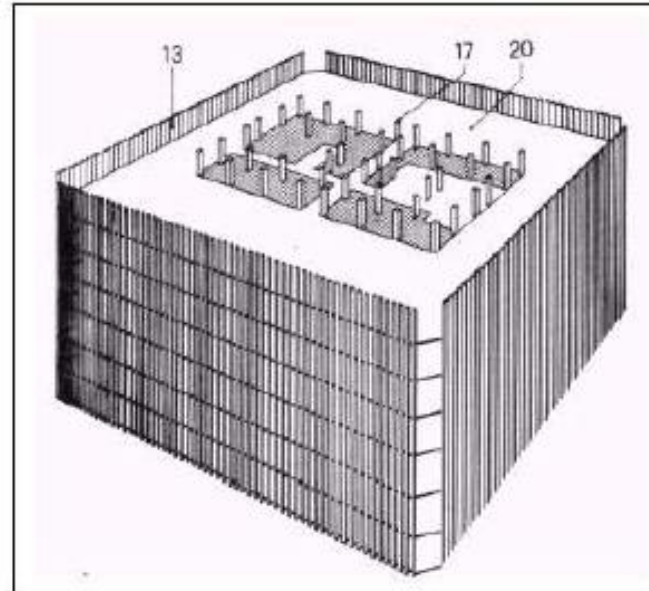


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



- Yangın ile kirişler kolonları dışarı doğru iter ve yangın katlarındaki kirişler burkulur ve yükü diğer katlara iletir.
- Burkulan kirişler, kolonlara çekme kuvveti uygular.
- Bu çekme-basınç kuvvet dalgası üst ve alt katlara doğru ilerler.





1. YÜKSEK YAPILAR SEMPOZYUMU
04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



BANKONE TOWER

49 KAT
179 m YÜKSEKLİK

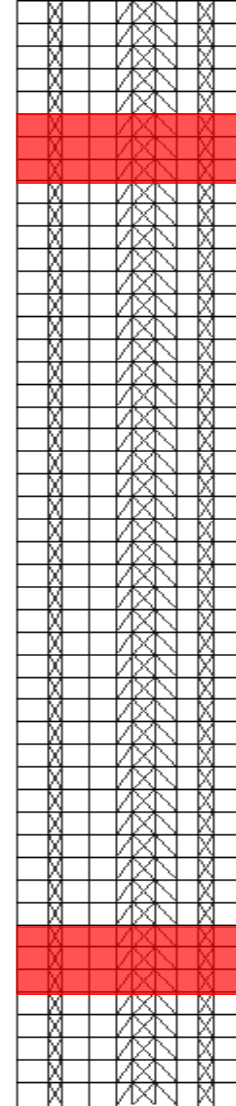
50 m

29 m



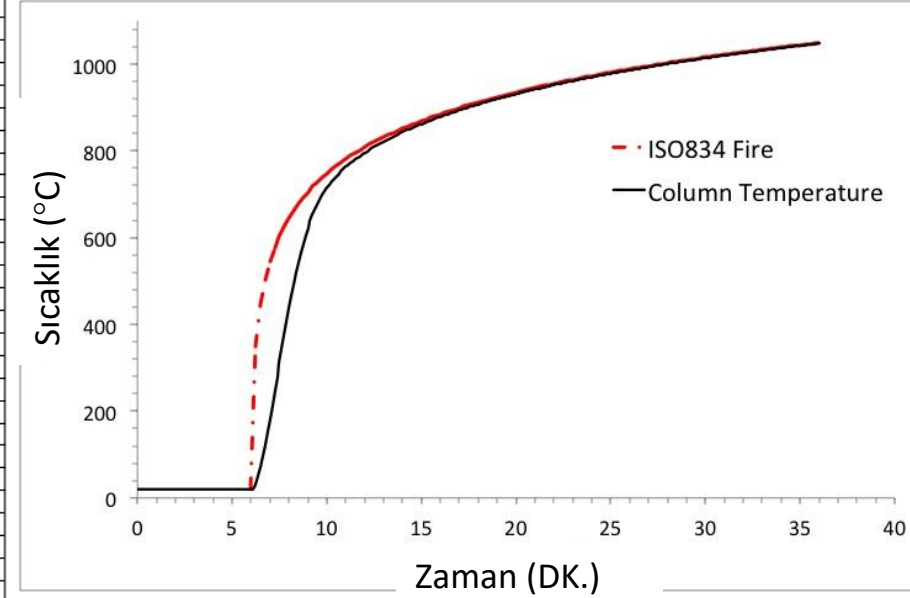
HİBRİT SİSTEM

Moment taşıyıcı ve merkezi çapraz sistemi



YANGIN

42nd Kat
41st Kat
40th Kat



YANGIN

7th Kat
6th Kat
5th Kat



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



❑ Bina Tipi

- Hibrit Yapı Sistemi: MRF (moment-taşıyıcı) and X-merkezi çapraz taşıyıcı
- İkincil kirişlerde kesme bağlantılar
- Kat yüksekliği : 3.6 m
- 15 cm beton döşeme

❑ Yapı yükleri (ETABS)

- DL: çelik eleman+döşeme, SDL: 3.6 kN/m², LL: 2.4 kN/m²
- Modal analiz
- Deprem bölgesi - Los Angeles, CA
- Bina periodu (T_d) = 2.62 sec
- Spektral ivme değerleri (S_s) = 2.12, 1-sn (S_1) = 0.78
- Taşıyıcı sistem davranış katsayısı (R) = 8, Bina önem katsayısı (I) = 3.



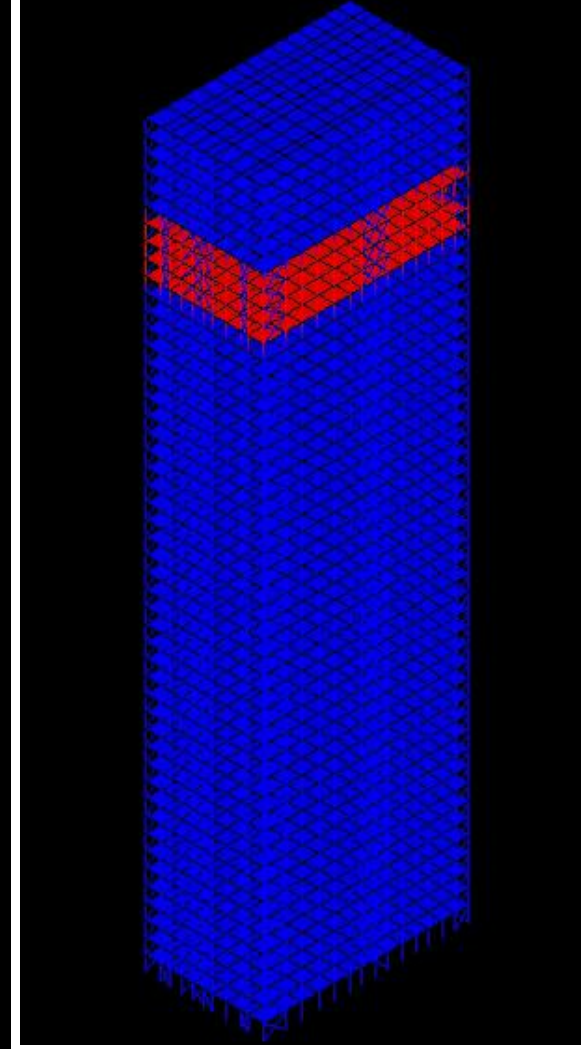
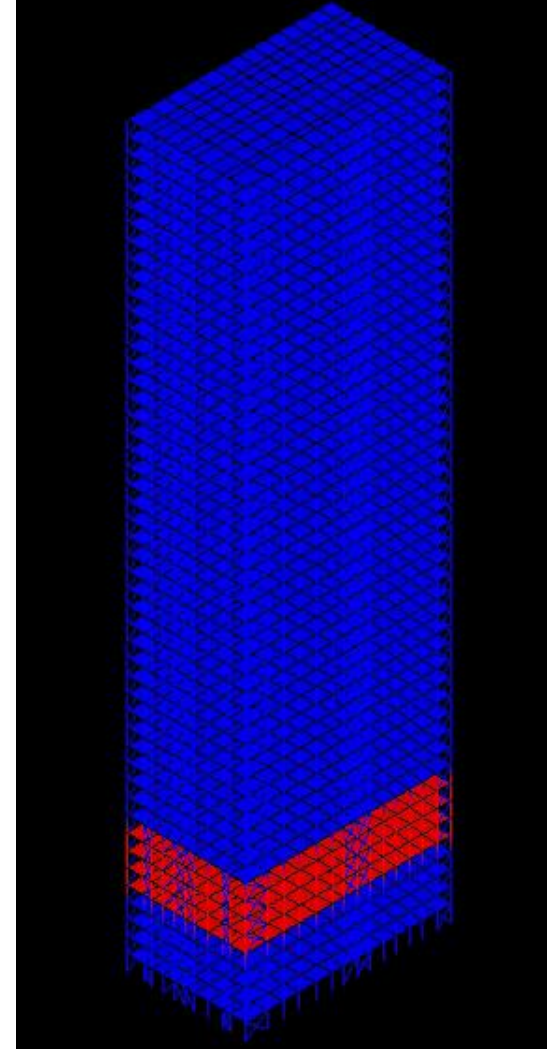
1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



❑ Quasi-Statik yüklemeli yangın analizi (LS-DYNA)

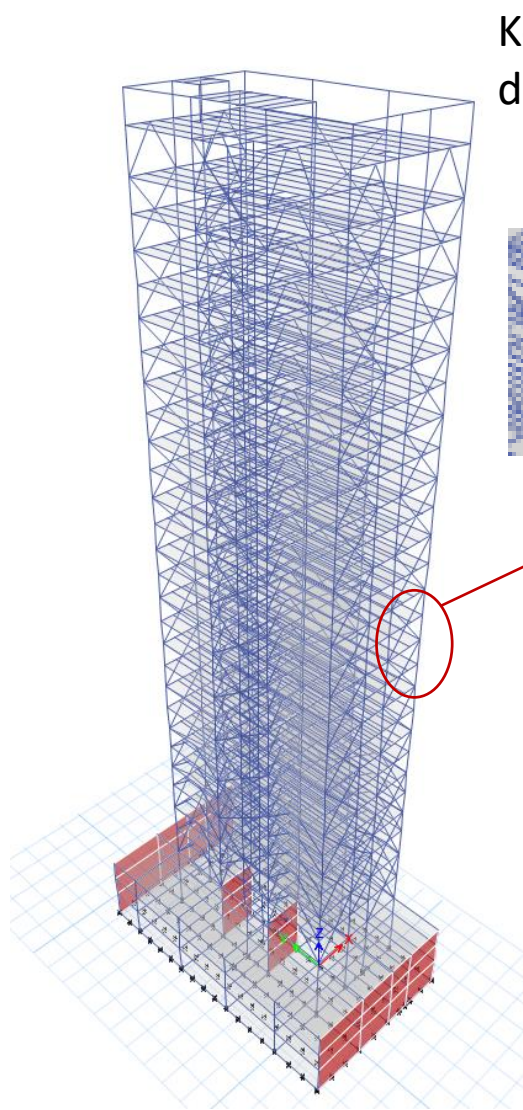
- Explicit zaman entegrasyonu
 - ISO834 Yangın eğrisi (2 saat, $T_{max} = 1050$ °C)
- Beton döşeme - Belytschko-Tsay kabuk elemanlar
- Çelik kiriş ve kolonlar (Hughes-Liu): 1-D toplu kütle yöntemi ile ısı transferi analizi
- Döşeme ve kirişler için yüzey kontakt elemanları
 - *CONTACT_SINGLE_SURFACE
 - *CONTACT_RIGID_SURFACE
- Eurocode'tan alınmış sıcaklığa bağlı değişken ısı özellikler
 - *MAT_ELASTIC_PLASTIC_THERMAL (MAT004)



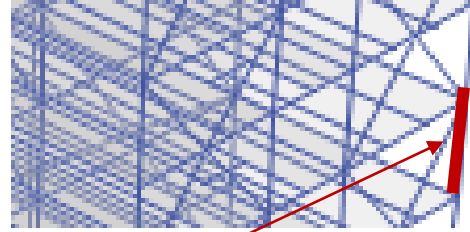


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



Kolon kaç dakika yangına dayanır?



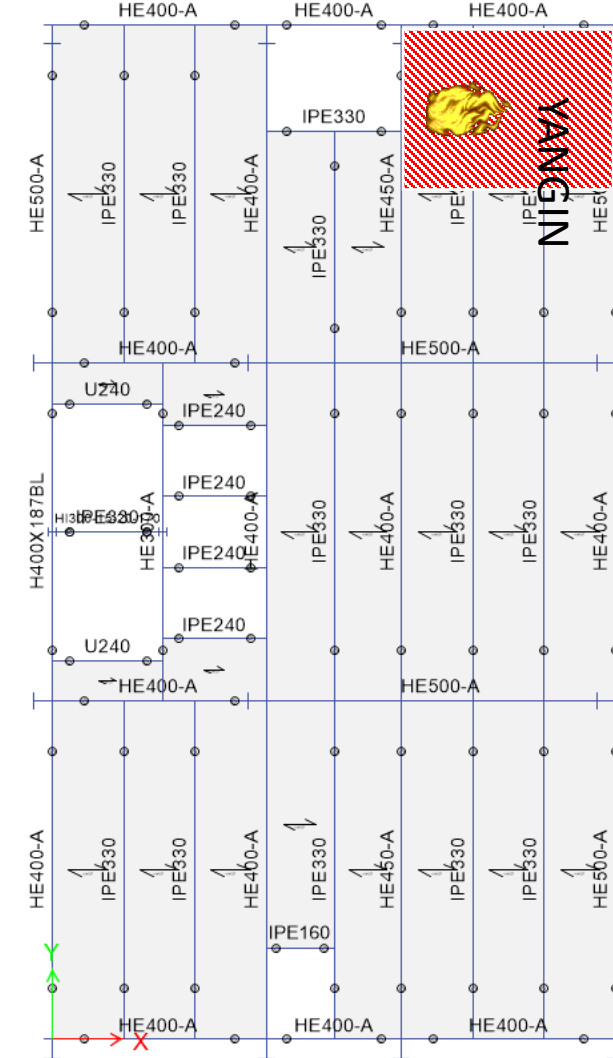
kolon



YANGIN

E (Yangın yükü) = 4209 MJ

Karyola, Yatak, Sandalye,
Gardırop

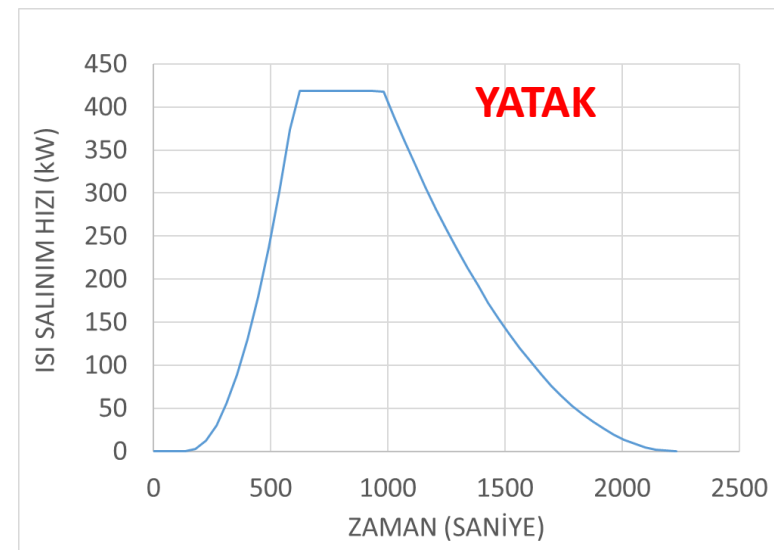
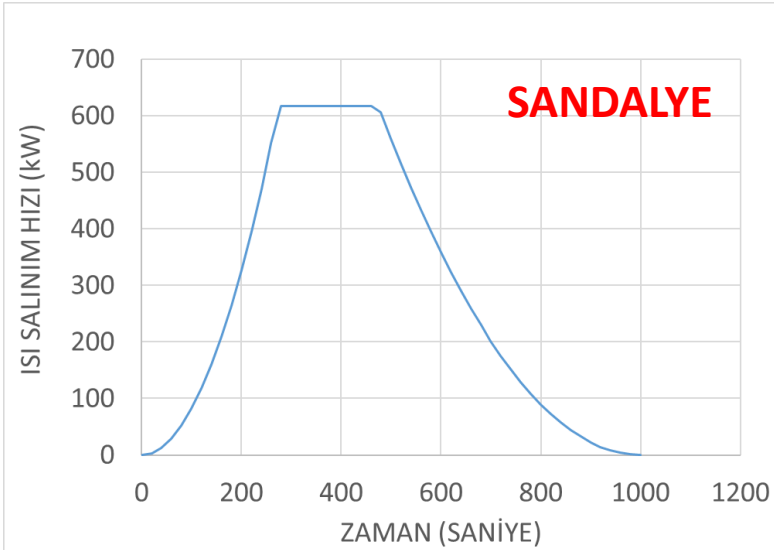
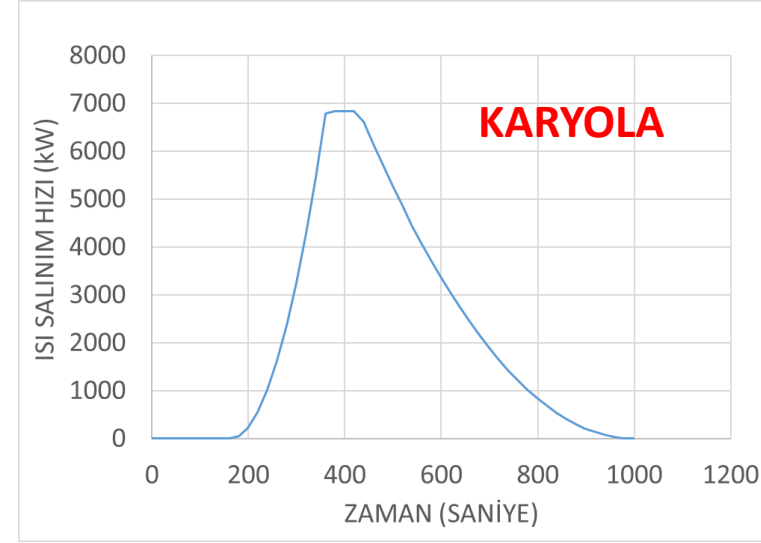
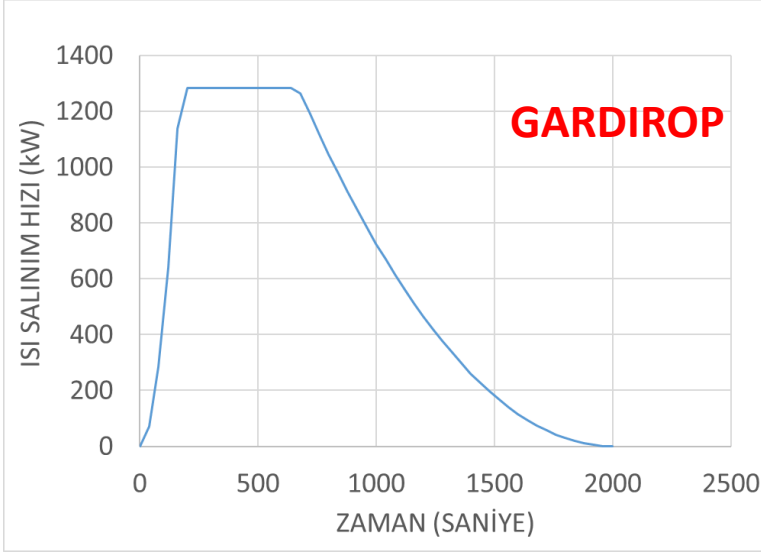




1. YÜKSEK YAPILAR SEMPOZYUMU

04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



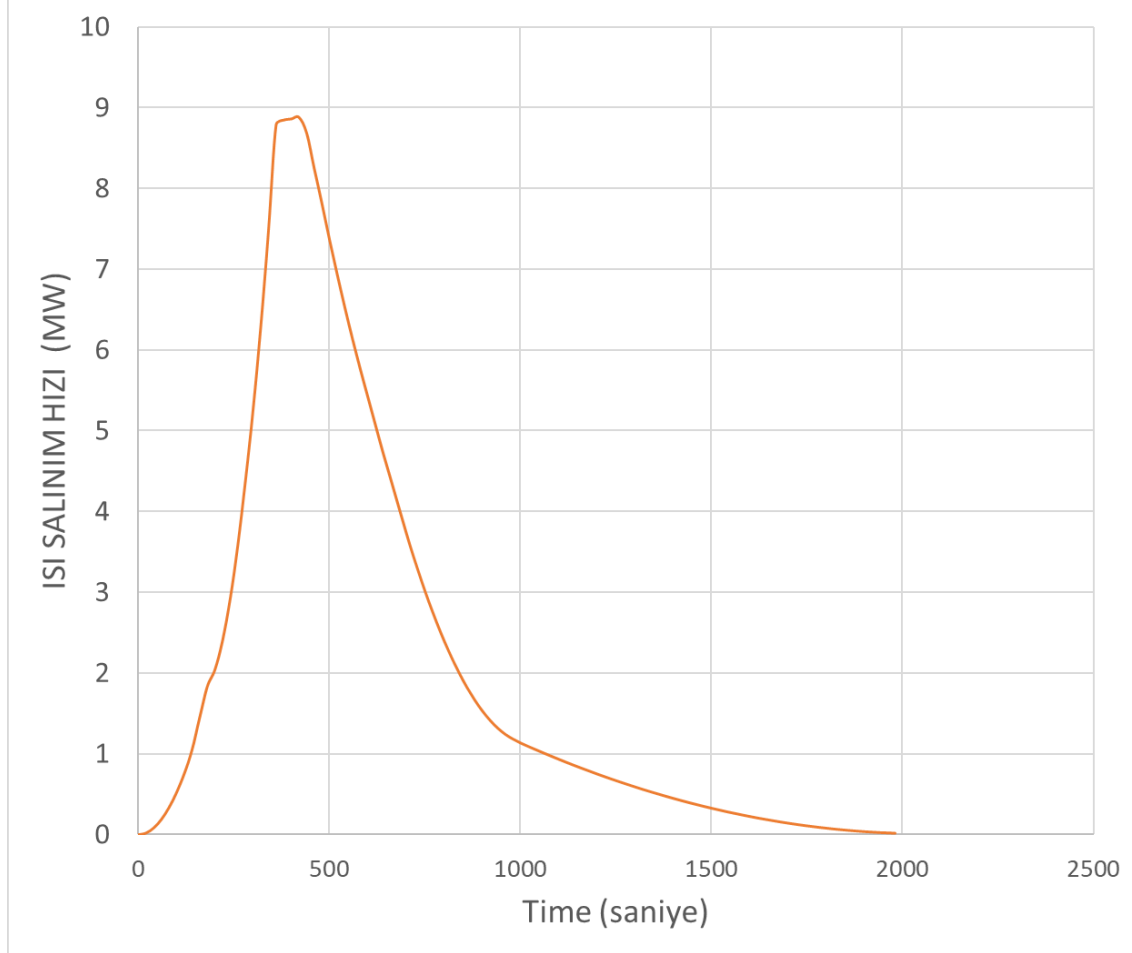


1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

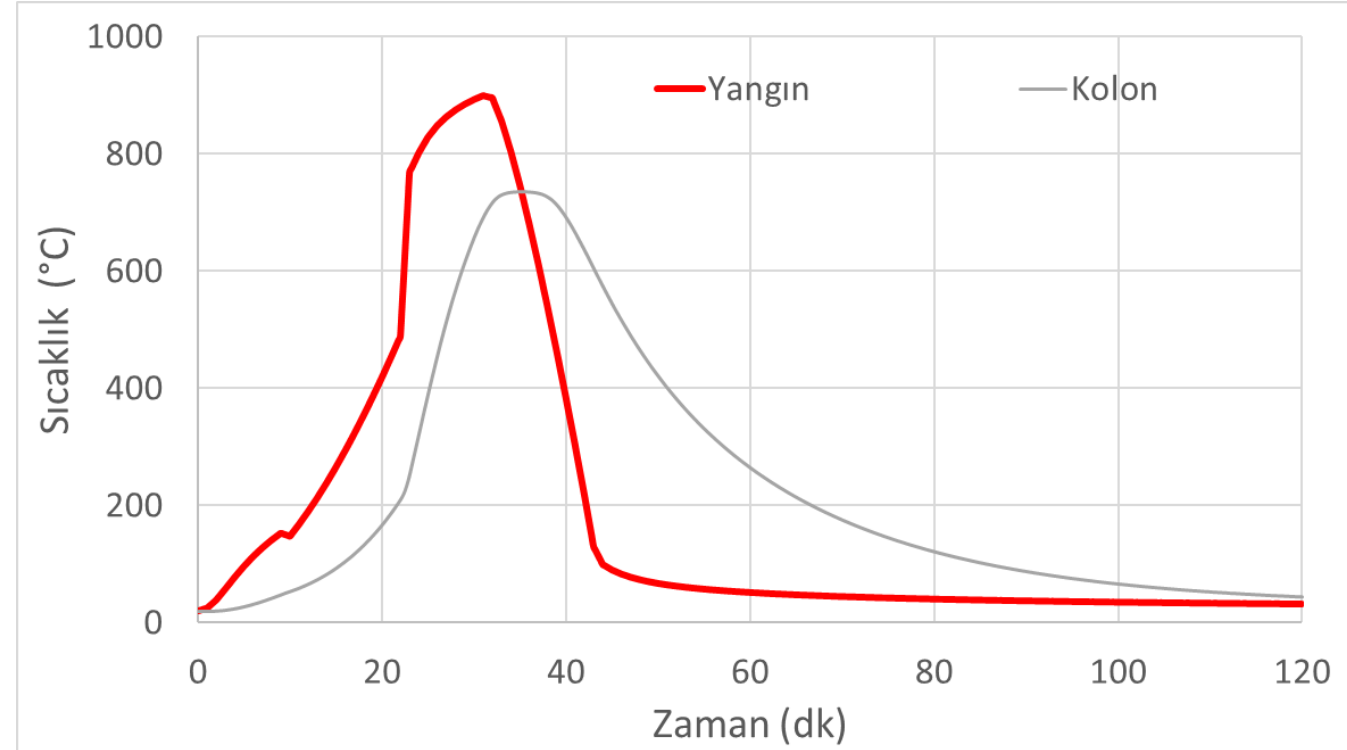
TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



I. TOPLAM ISI SALINIM HIZI (MW)



II. SICAKLIK EĞRİSİ VE KOLON SICAKLIĞI





1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI



III.

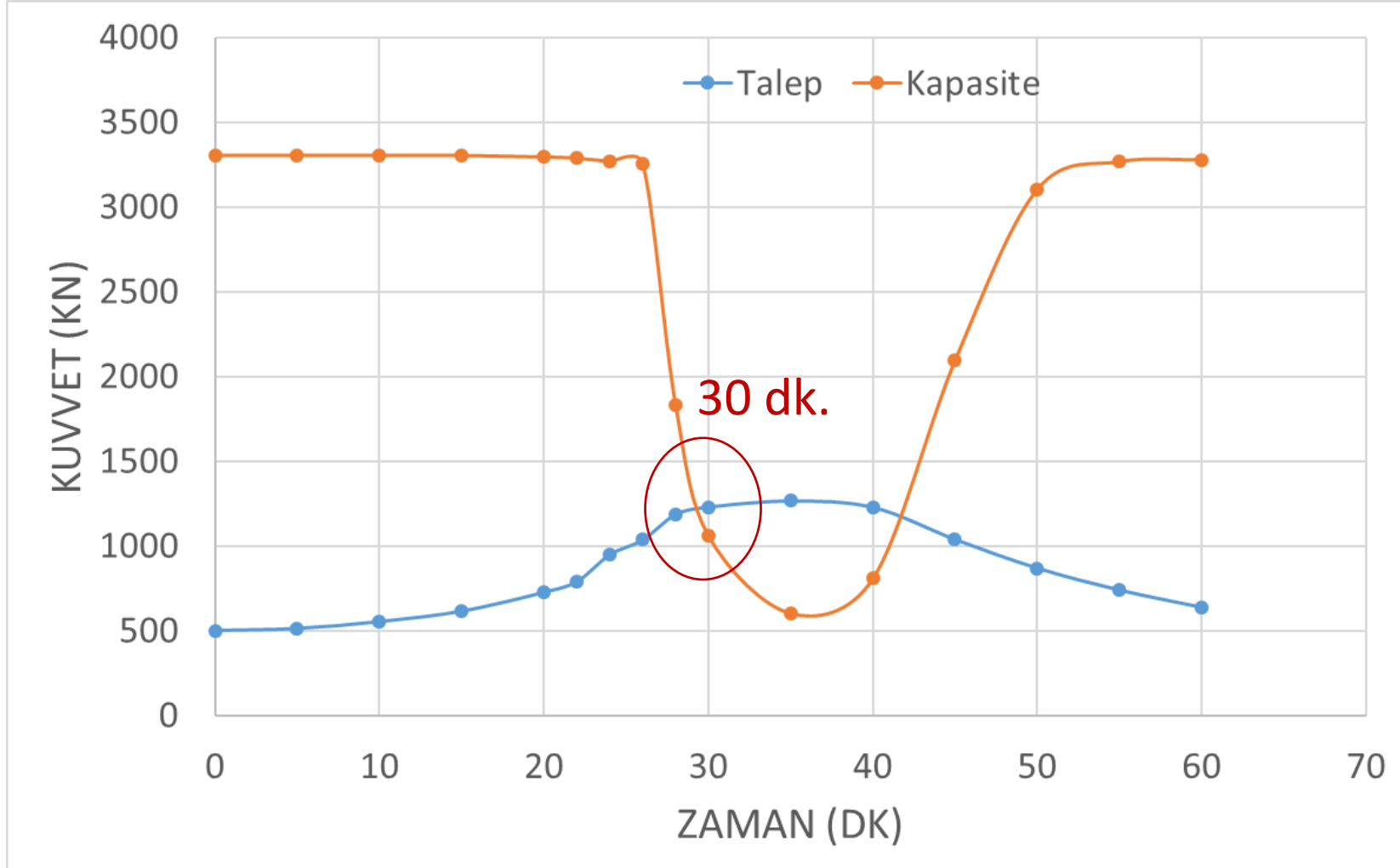


Zaman (dk)	Yangın Sıcaklığı	Yapı Sıcaklığı HEA 400	Yapıdaki Kuvvet Değişimi (Kn)	Yapının Kapasitesi (Kn)
0	20	20	500	3302
5	96	28	512.5	3302
10	148	54	553.0	3302
15	266	94	614.6	3302
20	419	168	726.3	3293
22	489	211	789.1	3286
24	802	325	948.2	3267
26	829	393	1036.1	3253
28	875	570	1185.9	1831
30	893	659	1230.0	1061
35	746	736	1265.9	604
40	384	691	1228.3	811
45	90	544	1038.4	2097
50	67	421	868.4	3104
55	57	331	738.8	3266
60	51	265	637.1	3277



1. YÜKSEK YAPILAR SEMPOZYUMU 04 – 05 MAYIS 2023 İSTANBUL

TMMOB
İNŞAAT MÜHENDİSLERİ ODASI





SORULARINIZ ?



<http://www.structuralfire.com>
<http://www.yapisalyangin.com>

Doç. Dr. Serdar SELAMET

İnşaat Mühendisliği Bölümü
Boğaziçi Üniversitesi
serdar.selamet@boun.edu.tr
Cell: +90-533-239-1254