

3.4 Assessment of the robustness of structures subjected to fire following earthquake through a performance-based approach (short version)

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Assessment of the robustness of structures subjected to fire following earthquake through a performance-based approach

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THE FIRE FOLLOWING EARTHQUAKE (FFE) HAZARD 2/15

GENERAL

- Earthquake
- Combination of unfavourable factors
- Fire

CATASTROPHE:
 The damage due to FFE can be larger than the one due to the earthquake itself

MAIN HISTORICAL RECORDS

Fire after 1923 Tokyo (Japan) Earthquake
 Fire after 1994 Northridge (USA) Earthquake
 Fire after 1995 Kobe (Japan) Earthquake
 Fire after 2009 Pandang (Indonesia) Earthquake

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THE FIRE FOLLOWING EARTHQUAKE (FFE) HAZARD 3/15

RISK MANAGEMENT APPROACH

A TWO-SCALES APPROACH

1. Regional scale 2. Building scale

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METHODOLOGICAL APPROACH 4/15

Methodology for the determination of the robustness of structures damaged by earthquake and subjected to fire

- Seismic damage**
 Determination of the structural performance in relation to the level of the seismic event
- Fire damage**
 Definition of the structural damage due to the fire
- Structural performance**
 Determination of the performance of the structure damaged by the earthquake and subjected to the fire

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1. SEISMIC DAMAGE 5/15

Seismic performance LEVELS (FEMA 356 Guidelines):

Operational (O)	Immediate Occupancy (IO)	Life Safety (LS)	Collapse prevention (CP)
Very light damage	Light damage	Moderate damage	Severe damage
<ul style="list-style-type: none"> No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable. 	<ul style="list-style-type: none"> No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional. 	<ul style="list-style-type: none"> Some residual strength and stiffness left in all stories. Gravity-load-bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair. 	<ul style="list-style-type: none"> Little residual stiffness and strength, but load-bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse.

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2. FIRE DAMAGE 6/15

Fire performance LEVELS: Structure should be designed for fire resistance and protected according to the performance objectives

Operational (Of)	Immediate Occupancy (IOF)	Life Safety (LSF)	Collapse prevention (CPT)
Very light damage	Light damage	Moderate damage	Severe damage
<ul style="list-style-type: none"> No permanent damage. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable. 	<ul style="list-style-type: none"> No permanent damage. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional. 	<ul style="list-style-type: none"> Some permanent damage. Damage to partitions. Minor damage to electricity and gas building networks Fire protection operable and activated Building may be beyond economical repair. 	<ul style="list-style-type: none"> Little residual stiffness and strength, but load-bearing columns and walls function. Large permanent damage. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Irreversible failure of electricity and gas building networks Failure of the fire protection systems Building is near collapse.

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EXAMPLE OF APPLICATION 7/15

STUDY CASE: STEEL FRAME

	δ/h [%]	Θ_{pl} [rad]
IO	1	0
LS	2	0.01-0.03
CP1	3.6	0.02-0.04
CP2	6.7	0.03-0.05

δ/h =interstory drift
 Θ_{pl} = plastic rotation

FIRE LOCATION

Case a
Case b
Case c
Case d

SEISMIC PERFORMANCE LEVEL

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2. FIRE DAMAGE 8/15

Fire performance LEVELS:

	Operational fire (Of)	Life Safe fire (LSf)	Section Collapse fire (CSf)	Local Collapse fire (CLf)	Global Collapse fire (CGf)
S	Attainment of the yield stress in the most stressed section	Formation of the first plastic hinge	Failure of the cross-section	Beam mechanism	Global mechanism
NS	Negligible damage	Equipments and contents are secure	Many architectural, mechanical and electrical systems are damaged	Extensive damage	

(S= Structural components; NS= Non structural components)

COUPLED THERMAL-MECHANICAL ANALYSES

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3. STRUCTURAL PERFORMANCE of structures damaged by seism and subjected to fire 9/15

SEISMIC DAMAGE (SEISMIC PERFORMANCE LEVEL):

- O: Operational
- IO: Immediate Occupancy
- LS: Life Safety
- CP: Collapse Prevention

EARTHQUAKE

FIRE DAMAGE AFTER EARTHQUAKE (FIRE AFTER SEISM PERFORMANCE LEVEL):

- Of: Operational fire
- LSf: Life Safe fire
- CSf: Section Collapse fire
- CLf: Local Collapse fire
- CGf: Global Collapse fire

FIRE POST-EARTHQUAKE

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EXAMPLE OF APPLICATION: seismic performance IO 10/15

SEISMIC DAMAGE:

Immediate Occupancy
 $\delta/h = 1\%$
 $\Theta_{pl} = 0$

	Of	LSf	CLf	CSf	CGf
Caso a	387	1304	1327	1408	1568
Caso b	310	1171	1192	1240	1490
Caso c	361	1198	1457	1468	1510
Caso d	387	1382	1451	1587	3076

Performance Fire levels

	Fire location	O _f	LS _f	CL _f	CS _f	CG _f
Case a						
Case b						
Case c						
Case d						

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EXAMPLE OF APPLICATION: seismic performance LS 11/15

SEISMIC DAMAGE:

Life Safe
 $\delta/h = 2\%$
 $\Theta_{pl} = 0.01-0.03$ rad

	Of	LSf	CLf	CSf	CGf
Caso a	0	0	1327	1408	1578
Caso b	0	0	1198	1235	1461
Caso c	0	0	1457	1468	1709
Caso d	0	0	1446	1574	3015

Performance Fire levels

	Fire location	O _f	LS _f	CL _f	CS _f	CG _f
Case a						
Case b						
Case c						
Case d						

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EXAMPLE OF APPLICATION: fire on half structure (case d) 14/15

FIRE ON HALF STRUCTURE

PERFORMANCE LEVELS

Performance Fire Levels (y)

Performance Structural Levels (x)

	IO	LS	CP1	CP2
Of	387	0	0	0
LSf	1382	0	0	0
CSf	1451	1446	1418	938
CLf	1587	1574	1544	1168
CGf	3076	2788	2340	1892

SEISMIC PERFORMANCE LEVEL

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