SUPPLEMENTAL MATERIAL

Section S1 – Demonstration of Equations (3) and (4) for the computation of *agu*

In accordance with Fajfar (Bento et al., 2004; Fajfar, 2000, 2002; Fajfar et al., 1988; Fajfar et al., 2005), the Seismic Demand, (Sd), for the equivalent SDOF system with Period (T*), can be determined using the Simplified N2 method as described below:

Sae Elastic response of an elastic SDOF with Period T*, when subjected to a Peak Surface Ground Acceleration, agS.

Sde Displacement of the elastic SDOF with Period T*, when subjected to a Peak Surface Ground Acceleration, agS.

TC The Characteristic Period of the Elastic Spectrum at the transition between Constant Accelerations and Constant Displacements.

T* The Elastic period of the equivalent SDOF.

Sdy (Or Dy*) The displacement of the equivalent SDOF at yielding.

Sdu The Ultimate displacement of the equivalent SDOF, before the formation of the last hinge (Pre-Collapse State).

Say The Yielding and Ultimate Capacity of the equivalent SDOF.

μ The structure Ductility defined by Sdu/Sdy.

Sad The Acceleration Demand reduced to take into account energy dissipation (Reduced Spectra).

Sd As already stated, the Inelastic (Displacement) Demand.

Rμ The reduction factor that by which Sad= Sae /Rμ.

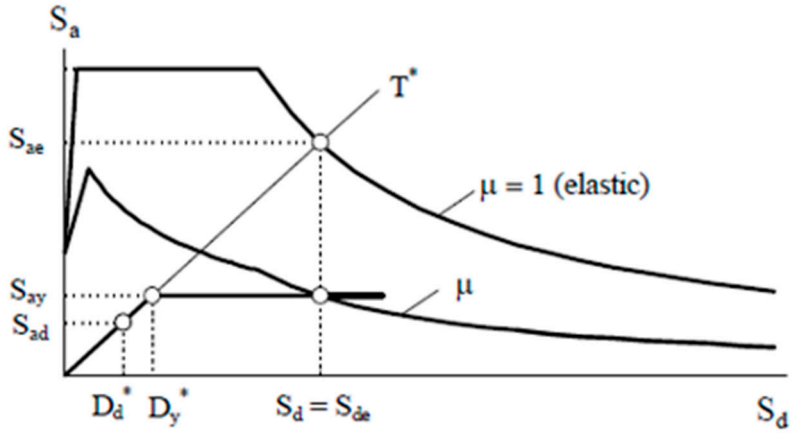


Figure S1 (Figure 5 in text) – Illustration of the N2 Method (retrieved from (Fajfar et al., 2005).

IN THE CASE THAT T* > TC

In accordance with the authors of N2, when the Elastic Period of the structure, T* is larger than the Period TC, the inelastic displacement demand Sd is equal to the elastic displacement demand Sde, with μ=Sd/Sdy.

For simplicity, we will define f(1;T*) the Demand of an Elastic SDOF, with Period T*, when subjected to a unitary peak ground acceleration ag=1. That is, the acceleration at the base of the SDOF is then agS.f(1;T*), being agS=ag.S.

Consequently, in this case, one arrives at:

$$Sd = Sd_e = Sa_e \cdot \left(\frac{T^*}{2\pi}\right)^2 = ag_S \cdot f(1;T^*) \cdot \left(\frac{T^*}{2\pi}\right)^2 = ag_S \cdot f(1;T^*) \cdot \frac{Sd_e}{Sa_e} \qquad \text{(S1)}$$

By the proposed definition, *agu* is the Peak Acceleration at the base of the structure that lead's it to it's Ultimate Displacement. In other words when agS = agu then Sd = Sdu.

Substituting in (S1), agS by *agu* and Sde by Sd, one gets

$$Sd = ag_S \cdot f(1;T^*) \cdot \frac{Sd}{Sa_e} \Rightarrow agu = ag_S = \frac{Sa_e}{f(1;T^*)} \qquad \text{(S2)}$$

However, as by definition Sae = Sad.μ and, and keeping in mind that we are in the range where T* > TC where Sad = Say, one gets to (S3).

$$agu = \frac{Sa_y}{f(1;T^*)} \cdot \mu \qquad \text{(S3)}$$

In accordance with (Bento, et al., 2004), the same behavior applies when Say > Sae, even when T* < TC.

IN THE CASE THAT T* < TC

In alignment with the authors of N2, when the Elastic Period of the structure, T* is smaller than the Period TC, the inelastic displacement demand Sd follow the same principles, having now the Reduction Factor Rμ following the behavior illustrated in Figure S2 (adapted from Vidic, et al., 1994).

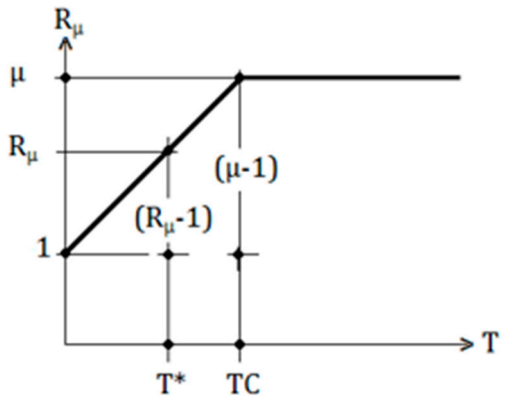


Figure S2 – Reduction Factor Rμ = f (T*, TC, μ) (adapted from Vidic, et al., 1994).

From Figure S2, it can be observed that for structures with Periods T*≥TC, the Reduction Factor is no longer the Ductility, meaning Rμ = μ. For rigid structures with T* < TC, using the equivalence of triangles, one arrives at:

$$T^* < TC: \quad \frac{R_\mu - 1}{T^*} = \frac{\mu - 1}{TC} \Rightarrow \mu = \frac{TC}{T^*}\left(R_\mu - 1\right) + 1 = \frac{TC}{T^*}\left(\frac{Sa_e}{Sa_y} - 1\right) + 1 = \frac{TC}{T^*}\left(\frac{ag_S . f(1,T^*)}{Sa_y} - 1\right) + 1$$

Similarly to the method described above, by assuming that the Ductility Demand reaches its maximum value of μ=Sdu/Sdy, and substituting agS with *agu*, the final equation becomes:

$$T^* < TC: \quad \mu = \frac{TC}{T^*}\left(\frac{agu . f(1,T^*)}{Sa_y} - 1\right) + 1 \Rightarrow \text{leading to:}$$

$$T^* < TC: \quad agu = \frac{Sa_y}{f(1,T^*)}\left[\left(\mu - 1\right).\frac{T^*}{TC} + 1\right] \qquad \text{(S4)}$$

The Equation (S4) can also be derived from (Fajfar, et al., 2005), as showed below, where now these authors prescribe the formulation as presented in Equation (S5).

$$Sd = Sde(T^*).\frac{\mu_p}{R_\mu}; \text{ with } \mu_p = \left(R_\mu - 1\right) \text{ and } R_\mu = \frac{Sae}{Say} \qquad \text{(S5)}$$

Developing Equation (S5), it comes

$$Sd = Sd_e.\frac{\mu_p}{R_\mu} = Sa_e.\left(\frac{T^*}{2\pi}\right)^2.\mu_p.\frac{Sa_y}{Sa_e} \Rightarrow Sd = Sa_y.\left(\frac{T^*}{2\pi}\right)^2.\mu_p = Sd_y.\mu_p$$

Again, when Sd = Sdu one gets

$$Sd = Sd_u = Sd_y.\mu_p \Rightarrow \mu = \frac{Sd_u}{Sd_y} = \mu_p = \left(R_\mu - 1\right)\frac{TC}{T^*} + 1 \Rightarrow$$

$$\mu = \left(\frac{Sa_e}{Sa_y} - 1\right)\frac{TC}{T^*} + 1 = \left(\frac{ag_S . f(1,T^*)}{Sa_y} - 1\right)\frac{TC}{T^*} + 1$$

Substituting agS with *agu* leads to the previous Equation (S4)

$$agu = \frac{Sa_y}{f(1,T^*)}\left[\left(\mu - 1\right).\frac{T^*}{TC} + 1\right]$$

SUMMARIZING

Using the N2 method, the Peak Acceleration at the base of some structure, *agu*, that causes the structure to reach it's Maximum Displacement, Sdu, can be succinctly expressed as follows.

For Less Rigid Structures with Periods T* > TC, their inelastic displacement is equal to the elastic displacement of a Linear SDOF Oscillator, with the same period, when subjected to the same acceleration ag at the base. In this case, the maximum base acceleration that causes the structure to reach its maximum displacement, Sdu at the edge of its Ultimate Damage Grade, in an imminent or Pre-Collapse situation is *agu* as defined in Equation (S6).

$$T^* \geq TC : agu = \frac{Sa_y}{f(1;T^*)}.\mu \qquad \text{(S6)}$$

For Rigid Structures, with Periods T* < TC, this ultimate acceleration, *agu* can be defined as in the following Equation (S7):

$$T^* < TC : \begin{cases} Say > Sae(T^*) : Sd = Sde \quad \text{and} \quad agu = \dfrac{Sa_y}{f(1;T^*)}.\mu \\ \text{else} \quad Sd = Sd_e.\dfrac{\mu_p}{R_\mu} \quad \text{and} \quad agu = \dfrac{Sa_y}{f(1,T^*)}\left[(\mu-1).\dfrac{T^*}{TC}+1\right] \end{cases} \qquad \text{(S7)}$$

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Section S2 – Values of *agu* for the 66 main typologies typified in this proposal

Table S1– *agu* values for the Portuguese Masonry Typologies

Epoch	Tipology	Floors	Floors	agu (m/s^2)
. . . 1755 . . .	Earth made (Taipa) or Earth Brick made (Adobe) Buildings	Wooden slabs	1 - 2	0,90
	"	"	3 - 4	0,50
	Rubble stone masonry	"	1 - 2	1,20
	"	"	3 - 4	0,90
1755 - 1850	Arches and Vaults in Massive Stone or Massive Clay bricks and rubble stone masonry walls with an embedded 3D Wooden Truss with St André Crosses, 1755-1870 ("Pombalino")	"	1 - 2	1,60
	"	"	3 - 4	1,45
	"	"	5 +	1,30
1850 - 1930	Rubble Stone with wooden slabs, Medium–High Rise, Lisbon 1870-1930 ("Gaioleiro")	"	1 - 2	1,05
	"	"	3 - 4	0,95
	"	"	5 +	0,75
1930 - 1940	Rubble Stone with Wooden Slabs, and RC slabs in the wet zones (Kitchen and Wc), Medium Rise 1930 - 1940	Concrete slabs in the wet zones and wooden slabs in the remaining floor.	1 - 2	1,50
	"	"	3 - 4	1,40
	"	"	5 +	1,30
1940 - 1950	Rubble Stone with RC slabs, only few RC Columns and Lintels on the outskirts, Medium Rise, Lisbon 1940 - 1950	RC slabs	1 - 2	1,30
	"	"	3 - 4	1,10
	"	"	5 +	0,90
	Rubble Stone with RC slabs, some RC Columns and Lintels, Medium Rise, Lisbon 1940 - 1950	"	1 - 2	2,30
	"	"	3 - 4	1,90
	"	"	5 +	1,50
1950 - 1960	Massive clay bricks in the lower floors and hollow clay bricks with RC slabs, some RC Columns, Lintels and Beams, Medium - High Rise, 1950 - 1960	"	1 - 2	3,20
	"	"	3 - 4	2,40
	"	"	5 - 7	1,60
	"	"	8 - 12	1,00

Table S2 – *agu* values for the Portuguese Reinforced Concrete Typologies

Epoch	Tipology	Floors	Floors	agu (m/s^2)
1960 - 1986	**Reinforced Concrete (RC) Frames**	RC slabs	1 - 2	3,50
	"	"	3 - 4	2,90
	"	"	5 - 7	2,40
	"	"	8 - 12	2,00
	Mixed RC structures (Columns & walls)	"	1 - 2	4,60
	"	"	3 - 4	4,30
	"	"	5 - 7	4,10
	"	"	8 - 12	3,90
	"	"	13 - 18	3,70
	"	"	19 +	3,70
1986 . . . 2000	**Reinforced Concrete (RC) Frames**	"	1 - 2	4,40
	"	"	3 - 4	4,10
	"	"	5 - 7	3,80
	"	"	8 - 12	3,65
	Mixed RC structures (Columns & walls)	"	1 - 2	5,80
	"	"	3 - 4	5,65
	"	"	5 - 7	5,50
	"	"	8 - 12	5,40
	"	"	13 - 18	5,20
	"	"	19 +	5,20
	RC Walls	"	1 - 2	6,30
	"	"	3 - 4	6,15
	"	"	5 - 7	6,00
	"	"	8 - 12	5,90
	"	"	13 - 18	5,70
	"	"	19 +	5,70

Epoch	Tipology	Floors	Floors	agu (m/s²)
2000 . . .	Reinforced Concrete (RC) Frames	"	1 - 2	4,90
	"	"	3 - 4	4,60
	"	"	5 - 7	4,40
	"	"	8 - 12	4,25
	Mixed RC structures (Columns & walls)	"	1 - 2	6,30
	"	"	3 - 4	6,15
	"	"	5 - 7	6,00
	"	"	8 - 12	5,90
	"	"	13 - 18	5,70
	"	"	19 +	5,70
	RC Walls	"	1 - 2	6,70
	"	"	3 - 4	6,55
	"	"	5 - 7	6,40
	"	"	8 - 12	6,30
	"	"	13 - 18	6,10
	"	"	19 +	6,10

Section S3 – Values of *agu* modifiers Δ considered in this proposal

Table S3 – Modifiers Δ

State of preservation		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Deterioration of Structural Elements	Not relevent	1,000	1,000	1,000	1,000
	Median	0,980	0,980	0,980	0,980
	Serious	0,967	0,970	0,970	0,970
	Very Serious	0,960	0,950	0,950	0,950
Deterioration of Coverage Elements	Not relevant	1,000			
	Median	0,980			
	Serious	0,967			
	Very Serious	0,960			
Deterioration of Ceilings or Pavements	Not relevant	1,000			
	Median	0,980			
	Serious	0,967			
	Very Serious	0,960			
Stairs deteriortion	Not relevant	1,000			
	Median	0,980			
	Serious	0,967			
	Very Serious	0,960			
Deterioration in outgoing elements (baconies, ...)	Not relevant	1,000			
	Median	0,980			
	Serious	0,967			
	Very Serious	0,960			

Interaction with adjacent buildings		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Contiguous buildings with different heights (difference of 2 or more floors)	None	1,000	1,000	1,000	1,000
	≠ 1 side	0,978	0,960	0,960	0,910
	≠ 2 sides	0,956	0,950	0,950	0,950
Contiguous buildings with uneven floors	None		1,000	1,000	1,000
	1 side		0,965	0,965	0,965
	2 sides		0,931	0,931	0,931
Block position	Middle	1,100	1,100	1,100	1,100
	Isolated	1,000	1,000	1,000	1,000
	Extreme	0,978	0,978	0,978	0,978
	Corner	0,956	0,956	0,956	0,956

Foundations ans soil conditions		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Sloping soils (15% +)	None	1,000	1,000	1,000	1,000
	Yes	0,925	0,925	0,925	0,925
Proximity to cliffs (less than 10m)	None	1,000	1,000	1,000	1,000
	Yes	0,850	0,850	0,850	0,850

Plan Irregularities		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Violation of EC8 criteria (Plan shapes: C, E, H, I, L,T, U, V, W, X, Y, ...)	None	1,000	1,000	1,000	1,000
	Yes	0,938	0,965	0,965	0,965
Plan slenderness ($L_{max} > 4 \times L_{min}$)	None	1,000	1,000	1,000	1,000
	Yes	0,960	0,875	0,875	0,925
Only a staircase or a unique set of nearby walls	None		1,000	1,000	1,000
	Central		0,875	0,750	0,800
	Excentric		0,750	0,650	0,700

Height irregularities		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Violation of EC8 criteria (Stairs, Recesses, Inverted Pendulums, ...)	None	1,000	1,000	1,000	1,000
	Yes	0,961	0,950	0,950	0,950
Interruption of masonry walls in one or two directions.	None	1,000			
	Yes	0,945			
Interruption of 70%+ of the area of Resistant Walls, in one or two directions, in lower floors (floors up to 30% of the total height)	None			1,000	
	Yes			0,400	
Interruption of less than 70% area of Resistant Walls, on lower floors (floors up to 30% of total height)	None			1,000	1,000
	Yes			0,600	0,600
Interruption of Resistant Walls in Intermediate Floors (floors between 30% and below 80% of the total height)	None	1,000		1,000	1,000
	Yes	0,961		0,800	0,800
Large openings, openings that are offset vertically or close to wedges	None	1,000			
	Yes	0,965			
Interruption of Pillars, Columns in lower floors. (floors up to 30% of the total height)	None	1,000	1,000	1,000	1,000
	Yes	0,953	0,700	0,900	0,850
Interruption of Pillars in intermediate floors. (floors above 30% and below 80% of the total height)	None	1,000	1,000	1,000	1,000
	Yes	0,969	0,800	0,925	0,900
Mass concentrations on floors or raised areas	None	1,000	1,000	1,000	1,000
	Yes	0,973	0,925	0,950	0,950
Floors with significantly higher height (h '> 1.5 x h) (h - height of regular floor, h '- height of floor)	None	1,000	1,000		
	Yes	0,977	0,925		
Empty Floors or Soft-Storey's: Floors with less than 50% of infill masonry panels than of contiguous floors.	None		1,000	1,000	
	Lower floors		0,800	0,975	
	Intermidiate floors		0,600	0,975	
Short collumns (h' ≤ h / 2) (h - height of regular floor, h '- height of floor)	None		1,000	1,000	
	Yes		0,850	0,950	
Stairs supported halfway between pillars	None		1,000	1,000	
	Yes		0,905	0,955	
Inclined pillars	None		1,000	1,000	1,000
	Yes		0,910	0,960	0,973

Other structural weaknesses		Δ_i Modifyers			
		Massonries	*RC Frames*	*RC Mixed*	*RC Walls*
Added floors	None	1,000			
	Yes	0,846			
Introduction of Water Supply Systems, Wastewater, Communications, Electricity, ... after the original construction.	None	1,000			
	Yes	0,983			
Introduction of Elevators after the original construction.	None	1,000			
	Yes	0,983			
Cover structure without Line or Strut	None	1,000			
	Yes	0,983			
Poor wall bracing for perpendicular walls. (4m or more between perpendicular walls)	None	1,000			
	Yes	0,983			
Slabs without beams.	None		1,000	1,000	1,000
	Yes		0,775	0,875	0,900
Evidence of differential settlements in foundations.	None	1,000	1,000	1,000	1,000
	Yes	0,983	0,875	0,888	0,888
Other ellemnts	None	1,000	1,000	1,000	1,000
	Yes	0,980	0,980	0,980	0,980

END