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THE BUILDING CODE SIA 269/8 FOR A RISK-BASED SEISMIC SAFETY ASSESSMENT AND RETROFIT OF STRUCTURES IN SWITZERLAND

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Abstract

This contribution presents the central concepts of the swiss building code SIA 269/8 [1] for the verification of the seismic safety of existing structures.

The first central concept of SIA 269/8 is the compliance factor. It indicates the degree of compliance of an existing structure in comparison with the requirements for new structures. The second central concept is the recommendation of measures based on the value of the compliance factor. If the seismic safety of an existing structure lies below a minimum threshold value of the compliance factor, retrofitting is mandatory to reach this minimum threshold whatever the costs. If the compliance factor is smaller than 1.0 and higher or equal to the minimum compliance factor, only efficient measures, with a risk reduction greater than the costs, have to be implemented.

The third central concept of SIA 269/8 is the evaluation of the commensurability of measures through the explicit computation of their efficiency. The risk reduction is computed using a set of standardized curves linking the compliance factor with different risk unit values. The efficiency is computed as the ratio between the risk reduction in Swiss francs (CHF) per year and the annualized cost of measures. For the computation of the risk reduction for human life, a value of statistical life of 10 million Swiss francs is used.

This elegant and relatively simple framework allows to focus retrofit measures for constructions with an unacceptable risk level as well as for constructions for which commensurate retrofit measures can be found. It has been widely applied in Switzerland since 2004 and is well accepted in practice.

Keywords: building code, existing structures, seismic safety, retrofit, risk-based

1. Introduction

The prestandard SIA 2018 [2] for the seismic safety verification and retrofit of existing buildings in Switzerland was published in 2004 and updated as the SIA 269/8 building code [1] in December 2017. SIA 269/8 extends the application domain to other construction types than buildings and extends the available standardized methodologies to compute the risk reduction through seismic retrofit measures to other risks than the risk to human life.

The risk-based concepts of SIA 2018 and SIA 269/8 have been applied since 2004 . They show an adequate balance between a consistent probabilistic risk-based framework and the necessary ease of use for a broad application in practice. A large number of seismic verifications and retrofits of existing buildings and bridges have been performed in Switzerland using these standards, such as documented in [3]. They usually happen in the framework of global retrofit or transformation projects.

2. Compliance factor and recommendation of measures

The first central concept of SIA 269/8 is the **compliance factor α_{eff}**, which indicates the degree of compliance of an existing structure with the requirements for new structures in the building code SIA 261 [4].

For constructions of importance class I (ordinary constructions, such as habitation and commercial buildings) and II (constructions with a higher human occupancy and content value), the **minimum compliance factor α_{min}** is 0,25. Below this minimum compliance factor, the safety of individuals is

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deemed unacceptable with an expected annual probability of death exceeding 10^{-5} (see also Fig. 2a). For constructions of importance class III (vital infrastructure function), II-s (school buildings) and II-i (important infrastructure function), the minimum compliance factor α_{min} is 0,40.

The second central concept of SIA 269/8 is the **recommendation of measures,** which is derived from the level of the compliance factor after a seismic safety verification (α_{eff}) such as depicted in Fig. 1.

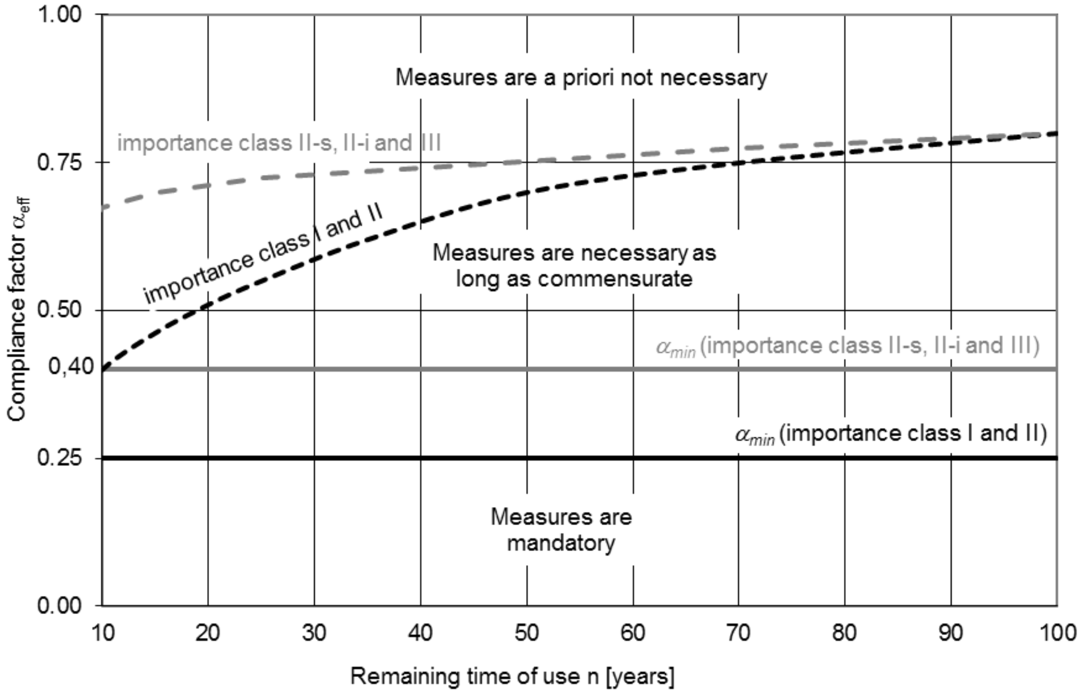

Fig. 1 - Recommendations of measures according to the new SIA building code 269/8.

Three cases are distinguished:

1. If the compliance factor α_{eff} is lower than α_{min}, retrofit measures are mandatory in order to reach a compliance factor after intervention (α_{int}) at least equal to α_{min}. The efficiency of possible further retrofit measures to achieve a higher compliance factor than α_{min} must be evaluated according to case 2.
2. If the compliance factor α_{eff} is between α_{min} and the dashed curve , then concepts for retrofit measures must be developed and implemented if they are *commensurate*. The objective is to reach a compliance factor of 1,0. If this is not possible, measures must be implemented until the limit of commensurability is reached. If no commensurate measures can be found then the level of seismic safety can be accepted as is.
3. If the compliance factor α_{eff} is above the dashed line in Figure 1, commensurate measures are probably impossible to find and the level of seismic safety can be accepted as is.

3. Computation of the commensurability of measures

In SIA 269/8 commensurate measures are defined as measures with an efficiency $EF_M \geq 1$. The efficiency of measures EF_M is defined as the ratio between the annualized risk reduction ΔR_M in Swiss francs per year and the annualized cost of measures SC_M (Eq. 1).

$$EF_M = \Delta R_M / SC_M \quad (1)$$

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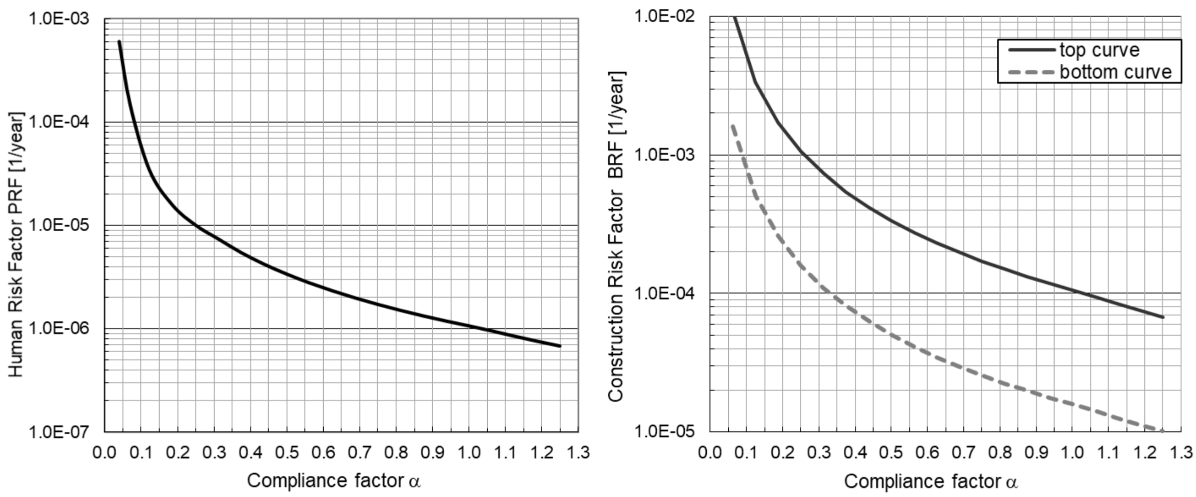
3.1 Computation of risk reduction

To compute the different components of the yearly risk reduction ΔR_M, SIA 269/8 provides standardized curves that link the compliance factor with different risk units (Fig 2.) or the willingness to pay to protect the infrastructure function (Fig. 3). The curves in Fig. 2 were derived from probabilistic risk studies such as in [5] and [6]. The curves in Fig. 3 were set based on the empirical observation of the willingness to pay for seismic retrofit measures by constructions with an important or vital infrastructure function. The risk curves in Fig. 2 are only used for the domain of compliance factors ≥ α_{min}, to compute the commensurability of measures.



(a) (b)

Fig. 2 – Human risk factor curve (a) and construction risk factor curve (b).

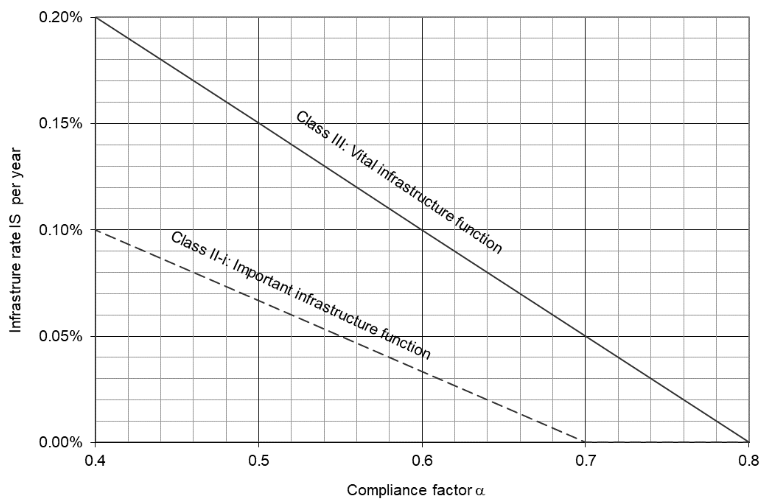


Fig. 3 – Infrastructure rate curves to compute the willingness to pay to protect the infrastructure function

Fig. 2a is a risk curve linking the compliance factor with the human risk factor *PRF*. *PRF* is the probability of death per year per unit of average human occupancy in the construction. The risk reduction related to human casualties ΔRP_M is computed according to Eq. (2) as the difference between the human risk factor ΔPRF_M before and after retrofit, multiplied by the average human occupancy in the construction *PB* and a value of statistical life *GRK* set as CHF 10 million.

$$\Delta RP_M = \Delta PRF_M \cdot PB \cdot GRK \tag{2}$$

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Fig. 2b has two risk curves linking the compliance factor with a construction risk factor *BRF*. *BRF* is the probability of loss per year per unit of the replacement value of the construction. The risk reduction related to the direct damage to the construction ΔRB_M is computed according to Eq. 3 as the difference between the construction risk factor ΔBRF_M before and after retrofit, multiplied by replacement value of the construction *BW*. For constructions with a high proportion of secondary elements, such as buildings, the upper curve in Fig. 2b is used. For constructions with a low proportion of secondary elements, such as bridges or retaining walls, the lower curve in Fig. 2b is used.

$$\Delta RB_M = \Delta BRF_M \cdot BW \tag{3}$$

SIA 269/8 also provides methods to estimate the risk reduction for the content value ΔRS_M as well as the business interruption ΔRU_M. The computation of ΔRS_M and ΔRU_M is based on ΔBRF_M according to Fig. 2b. ΔRS_M is computed according to Eq. (4) as ΔBRF_M multiplied by the replacement value of the content *SW* that can be damaged by the construction collapse and a calibration factor *SRF*. Depending on the situation *SRF* take on value of 0.05 or 0.2. ΔRU_M is computed according to Eq. (5) as ΔBRF_M multiplied by the cost of business interruption *UK* over the estimated interruption time and a calibration factor *URF* of 0.5. For ordinary buildings, ΔRS_M and ΔRU_M are usually negligible.

$$\Delta RS_M = SRF \cdot \Delta BRF_M \cdot SW \tag{4}$$

$$\Delta RU_M = URF \cdot \Delta BRF_M \cdot UK \tag{5}$$

For constructions of importance class III (vital infrastructure function) and II-i (important infrastructure function), the efficiency of measures is computed using the concept of willingness to pay to protect the infrastructure function ΔZI_M. ΔZI_M is computed using Fig. 3, which relates a so-called infrastructure rate *IS* with the compliance factor. ΔZI_M is computed according to Eq. (6) as the difference in infrastructure rate ΔIS_M before and after retrofit multiplied by the replacement value of the construction and the directly impacted goods *BSW* (usually the value of the construction and its content).

$$\Delta ZI_M = \Delta IS_M \cdot BSW \tag{6}$$

The total risk reduction ΔR_M for constructions of importance classes COI, COII and COII-s is the sum of the risk reduction contributions such as given by Eq. (7). The total risk reduction ΔR_M for constructions of importance classes COII-i and COIII is given by Eq. (8).

$$\Delta R_M = \Delta RP_M + \Delta RB_M + \Delta RS_M + \Delta RU_M \tag{7}$$

$$\Delta R_M = \Delta RP_M + \Delta ZI_M \tag{8}$$

According to SIA 269/8, it is mandatory to consider the risk reduction for human casualties ΔRP_M and the willingness to pay to protect the infrastructure function ΔZI_M for the computation of the efficiency of measures. It is only recommended to consider other risk reductions such as ΔRB_M, ΔRS_M, ΔRU_M.

3.2 Computation of the yearly cost of measures

The yearly cost of measures SC_M is computed according to Eq. (9) as the cost of retrofit measures SIC_M multiplied by a discounting factor *DF*. *DF* is determined according to Eq. (10) using the remaining time of use of the construction *dr* in years and a discounting rate *i* of 2 % per year.

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$$SC_M = SIC_M \cdot DF \tag{9}$$

$$DF = i \cdot (1 + i)^{dr} / [(1 + i)^{dr} - 1] \tag{10}$$

3.3 Computation of limit costs for commensurable measures

Using the equations presented in 3.1 and 3.2, it is possible to compute the limit costs of retrofit measures so that EF_M= 1.0 for a known initial situation and a target compliance factor after retrofit. The general formulation for these limit costs SIC_{Mlim} is given in Eq. (11), with ΔR_M being the risk reduction that is obtained with the target compliance factor. SIC_{Mlim} is useful to assess the approximate maximum budget that could be justified for commensurate retrofit measures.

$$SIC_{Mlim} = \Delta R_M / DF \tag{9}$$

4. Examples

4.1 Office building

The initial compliance factor for the office building is 0.3 (above the minimum required compliance factor of 0.25). For this example, the risk reduction for human life (mandatory) as well as the risk reduction for the direct damage to the building (owner's decision) are considered in the evaluation of the efficiency of possible retrofit measures. The values of the relevant parameters are given in Table 1.

Table 1 – Example of an office building

Parameter	Value	Description / Comment
Importance class	I	Office building
dr	50 years	Remaining life time of the building
PB	21 persons	Average human occupancy 100 employees, 8 hours a day, 5 days a week, 47 weeks a year : $PB = 100 \cdot 8/24 \cdot 5/7 \cdot 47/52 \sim 21$
BW	CHF 8 million	Building replacement value.
α_{eff}	0.3	Compliance factor after seismic verification.
α_{int}	0.8	Compliance factor after the considered retrofit measures.
SIC_M	CHF 150'000	Cost of the retrofit measures.
SC_M	CHF 4'800 / year	Yearly cost of the retrofit measures according to Eq. (9) with a discounting factor DF = 0.032 according to Eq. (10).
ΔRP_M	CHF 1'260 / year	Risk reduction for human life. Eq. (2) with $\Delta PRF \sim 6 \cdot 10^{-6}$ per year according to Fig 2a.
ΔRB_M	CHF 4'800 / year	Risk reduction for direct damage to the building. Eq. (3) with $\Delta BRF \sim 6 \cdot 10^{-4}$ / year according to Fig 2b, upper curve.
ΔR_M	CHF 6'620 / year	$\Delta RP_M + \Delta RB_M$
EF_M	1.3	$EFM \geq 1.0$. Measures must be implemented.
SIC_{Mlim}	CHF 207'000	Limit costs for commensurable measures $\Delta R_M / DF$

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The proposed retrofit measures have an efficiency EF_M = 1.3 (> 1.0) and must be implemented. If only the risk reduction to human life had been considered (owner's decision), the efficiency of the proposed measure would be EF_M = 0.3 (<< 1.0).

4.2 School building

The initial compliance factor is below the required minimum compliance factor of 0.4. A seismic retrofit to reach the minimum compliance factor of 0.4 is mandatory. In this example the efficiency of additional retrofit measures to try to reach a compliance factor of 1.0 is evaluated. As in example 1, the risk reduction to human life (mandatory) as well as the risk reduction for direct damage to the building (owner's decision) are considered. The values of the relevant parameters are given in Table 2.

Table 2 – Example of a school building

Parameter	**Value**	**Description / Comment**
Importance class	II-i	School building
dr	50 years	Remaining life time of the building
PB	55 persons	Average human occupancy
BW	CHF 4 million	Building replacement value.
α_{eff}	0.4	Compliance factor after initial mandatory retrofit.
α_{int}	1.0	Compliance factor after the considered additional retrofit measures.
SIC_M	CHF 60'000	Cost of the retrofit measures.
SC_M	CHF 1'920 / year	Yearly cost of the retrofit measures according to Eq. (9) with a discounting factor DF = 0.032 according to Eq. (10).
ΔRP_M	CHF 2'200 / year	Risk reduction for human life. Eq. (2) with $\Delta PRF \sim 4{\cdot}10^{-6}$ per year according to Fig 2a.
ΔRB_M	CHF 1'600 / year	Risk reduction for direct damage to the building. Eq. (3) with $\Delta BRF \sim 4{\cdot}10^{-4}$ per year according to Fig 2b, upper curve.
ΔR_M	CHF 3'800 / year	$\Delta RP_M + \Delta RB_M$
EF_M	1.7	EFM ≥ 1.0. Measures must be implemented.
SIC_{Mlim}	CHF 127'000	Limit costs for commensurable measures $\Delta R_M / DF$

In this case, the proposed additional retrofit measures have an efficiency EF_M = 1.7 (> 1.0) and must be implemented. If only the risk reduction to human life had been considered, the efficiency of the proposed measure would be EF_M = 1.1 (> 1.0), still justifying the additional retrofit measures to achieve a compliance factor of 1.0.

4.3 Hospital building

The initial compliance factor for the hospital building is 0.5 (above the minimum required compliance factor of 0.4). For this example, the risk reduction to human life (mandatory) as well as the willingness to pay to protect the infrastructure function (mandatory) are considered in the evaluation of the efficiency of possible retrofit measures. The values of the relevant parameters are given in Table 3.

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Table 3 – Example of a hospital building

Parameter	**Value**	**Description / Comment**
Importance class	III	Hospital building with emergency and intensive care unit
dr	50 years	Remaining life time of the building
PB	110 persons	Average human occupancy
BW	CHF 135 million	Building replacement value.
SW	CHF 55 million	Content's value
α_{eff}	0.4	Compliance factor in the initial condition $\alpha_{eff} \geq \alpha_{min}$ = 0.4.
α_{int}	1.0	Compliance factor after the considered retrofit measures.
SIC_M	CHF 2 million	Cost of the retrofit measures.
SC_M	CHF 64'000 / yr	Yearly cost of the retrofit measures according to Eq. (9) with a discounting factor DF = 0.032 according to Eq. (10).
ΔRP_M	CHF 4'400 / year	Risk reduction for human life. Eq. (2) with $\Delta PRF \sim 4 \cdot 10^{-6}$ per year according to Fig 2a.
ΔZI_M	CHF 380'000 / yr	Willingness to pay to protect the infrastructure function. Eq. (6) with ΔIS_M = 0.2% per year according to Fig 3, upper curve and BSW = BW + SW..
ΔR_M	CHF 384'400 / yr	$\Delta RP_M + \Delta ZI_M$
EF_M	6.0	EFM ≥ 1.0. Measures must be implemented.
SIC_{Mlim}	CHF 12 million	Limit costs for commensurable measures $\Delta R_M / DF$

The proposed retrofit measures have an efficiency EF_M = 6.0 (> 1.0) and must be implemented. The willingness to pay for the protection of the infrastructure function largely dominates the risk reduction in the computation of the efficiency of measures. The computation of limit costs for commensurable measures SIC_{Mlim} amounts to CHF 12 million. This represents 6.3% of the building and content value. Only taking into account the risk reduction to people would reduce SIC_{Mlim} to only CHF 137'000 (only around 0.1 % of the building replacement value).

4.4 Highway bridge

The initial compliance factor for the bridge is 0.4 (equal to the minimum required compliance factor of 0.4). For this example, the risk reduction to human life (mandatory) as well as the willingness to pay to protect the infrastructure function (mandatory) are considered in the evaluation of the efficiency of possible retrofit measures. The values of the relevant parameters are given in Table 4.

The proposed retrofit measures have an efficiency EF_M = 2.0 (> 1.0) and must be implemented. The willingness to pay for the protection of the infrastructure function largely dominates the risk reduction in the computation of the efficiency of measures. The computation of limit costs for commensurable measures SIC_{Mlim} amounts to CHF 800'000. This represents 4.0% of the bridge replacement value.

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Table 4 – Example of a highway bridge

Parameter	**Value**	**Description / Comment**
Importance class	II-i	Highway bridge with an important infrastructure function
dr	80 years	Remaining life time of the building
PB	1 person	Average human occupancy is negligible
BW	CHF 20 million	Building replacement value.
SW	CHF 0.1 million	Content's value is negligible
α_{eff}	0.4	Compliance factor in the initial condition $\alpha_{eff} \geq \alpha_{min} = 0.4$.
α_{int}	1.0	Compliance factor that can be reached with the considered additional retrofit measures.
SIC_M	CHF 400'000	Cost of the retrofit measures.
SC_M	CHF 10'000 / year	Yearly cost of the retrofit measures according to Eq. (9) with a discounting factor DF = 0.025 according to Eq. (10).
ΔRP_M	CHF 0 / year	Risk reduction for human life. Eq. (2) with $\Delta PRF \sim 4 \cdot 10^{-6}$ per year according to Fig 2a.
ΔZI_M	CHF 20'000 / year	Willingness to pay to protect the infrastructure function. Eq. (6) with $\Delta IS_M = 0.1\%$ per year according to Fig 3, lower curve and BSW = BW + SW.
ΔR_M	CHF 20'000 / year	$\Delta RP_M + \Delta ZI_M$
EF_M	2.0	EFM ≥ 1.0. Measures must be implemented.
SIC_{Mlim}	CHF 800'000	Limit costs for commensurable measures $\Delta R_M / DF$

5. Concluding remarks

The building code SIA 269/8 was published in 2017 on the basis of the prestandard SIA 2018 from 2004. Many buildings and other constructions have been verified and retrofitted using these standards in Switzerland.

The minimum compliance factor ensures that constructions with a very insufficient seismic safety have to be retrofitted up to a minimum standard. For situations where the minimum compliance factor is reached, the computation of the efficiency of measures helps to discriminate situations for which a seismic retrofit is justifiable from situations where it is not.

It should be stressed that the computation of the efficiency of measures is not the only criteria to decide a seismic retrofit. The ratio between the cost of a construction project (cost of global retrofit or transformation) and the cost of the seismic retrofit measures is also an important parameter to consider. If the cost of a seismic retrofit becomes negligible in relation to the cost of the whole construction project, the measures should be implemented regardless of the value of EF_M.

Further detailed information is available in French and German in a downloadable documentation of the Swiss Society for Earthquake Engineering and Structural Dynamics (www.sgeb.ch)

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