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SPECIFIED DAMAGE PATTERNS FOR CALIBRATION OF EARTHQUAKE CODE REGULATIONS

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SUMMARY

In the new Swiss earthquake code regulations, "Specified Damage Patterns" serve as an excellent tool for calibration of the earthquake protection provisions. The Specified Damage Patterns define the accepted damage for different Structural Classes under the action of the design earthquake. On the other hand, the expected damage depends primarily on the inelastic deformations of the force-bearing structure represented by the deformation factor, which can also be called an "accepted overall displacement ductility factor". Hence, the deformation factor has to be assessed with respect to the Specified Damage Pattern of the relevant structural class. Additionally, the resulting seismic forces can be reduced by a factor taking into account the difference between design resistance and effective resistance of the structure.

INTRODUCTION

This contribution deals with the seismic design philosophy applied by the new Swiss earthquake code regulations, which are part of the new Swiss Code "Actions on structures" [1]. The new regulations have a structure and content similar to other new earthquake codes, e.g. [2], but in one very important point there is a decisive difference: A concept with so-called "Specified Damage Patterns" for the different Structural Classes is used instead of the wellknown importance factors. This concept allows not only a clear understanding of the objectives of the seismic design but also allows by a rational way to assess the seismic design forces to a generally acceptable level.

MAIN FEATURES OF THE NEW SWISS EARTHQUAKE REGULATIONS

Switzerland has a low to medium seismicity. In the year 1356 Basle was hit and highly damaged by an earthquake with an estimated epicentral intensity of 9 to 10 [MSK]. The actual seismic risk at Basle is predicted to have an intensity [MSK] of 7.4 for a recurrence probability of 1:1000 p.a.. A fairly higher actual seismic risk lies in the alpine region of the Rhône Valley with a maximum intensity [MSK] of 8.7 for 1:1000 p.a.. But also in the highly populated and industrialised midland region with the towns of Geneva, Berne, Zürich and St. Gall some minor earthquakes cannot be excluded. Therefore, a revision of the Swiss earthquake code regulations dating back to the late sixties and working with small seismic coefficients of 0.02 to 0.05 g was justified. From 1980 to

1988 completely new and modern earthquake code regulations were worked out. They will come into force in March 1989.

In the following the main features of the new regulations are shortly described.

Conceptional and Constructional Measures

In many cases a suitable architectural and structural concept and adequate constructional details contribute as much to a satisfying earthquake behaviour of a structure as do design calculations. Thus, considerable emphasis is given to conceptional and constructional measures. They contain clauses and rules concerning the following aspects:

Buildings:
: Symmetry and regularity of the force-bearing structure in plan and elevation; constructional details; joints between adjacent buildings; foundation; secondary elements (partitions, parapet walls, facades, ceiling, etc.).

Bridges:
: Constructional details; joints; support regions; foundations.

Earth-retaining walls and embankments:
: Special measures.

Plant and equipment (pipes, containers, laboratory equipment, machines, ventilation, lighting, etc.):
: Structural form and fixing; making differential movements possible.

The enforcement of these measures depends on the combination of Seismic Zone/ Structural Class. Three different enforcement categories were introduced for buildings and bridges.

Seismic Zones

Switzerland is divided into four zones. An average design intensity [MSK] is assigned to each zone based on a recurrence probability of 1:400 p.a.. To the design intensity an effective maximum ground acceleration is assigned based on wellknown correlations as follows:

Zone	Intensity [MSK]	Maximum ground acceleration
1	6 - 7	0.06 g
2	7+	0.10 g
3	7 - 8	0.13 g
4	8	0.16 g

Elastic Design Spectra

An elastic design acceleration spectrum is used according to stiff or medium stiff soils corresponding with the specific Swiss conditions of source mechanisms, geology, etc. The spectra represent average values (50% fractile) for a damping coefficient of 5% critical. The plateau in the range of 3 to 10 Hz for stiff and 2 to 10 Hz for medium stiff soils as compared to the rigid-body acceleration (maximum ground acceleration) corresponds to an amplification factor of 2.12.

Equivalent Lateral Seismic Force

The total equivalent lateral seismic force for buildings and bridges is given by the simple formula

$$Q_{acc} = \frac{a_h}{g} \cdot \frac{C_d}{K} \cdot (G_m + Q_r + Q_{d,acc}) \qquad (1)$$

where: Q_{acc} : total equivalent lateral seismic force

a_h : horizontal acceleration from the elastic design spectrum, depending on the seismic zone, on the soil conditions and on the fundamental frequency of the structure

g : acceleration due to gravity

K : deformation factor depending on the Structural Class and the Structural Type (see below)

C_d : design factor (see below)

G_m : self-weight of the structure

Q_r : characteristic value of other dead loads

$Q_{a,acc}$: live load likely to occur simultaneously with the earthquake

Structural Classes

Each structure of the groups
- buildings
- bridges
- earth-retaining walls and embankments
- plant and equipment

has to be assigned to one of the three Structural Classes I, II or III. The criteria for this assignment are described below.

Structural Types

Each structure has to be assigned to one of the five Structural Types for resisting horizontal forces. The Structural Types are listed in Table 3. For each Structural Type (and for each Structural Class) different values of the deformation factor have to be used.

CLASSIFICATION OF STRUCTURES BY HELP OF SPECIFIED DAMAGE PATTERNS

For each of the Structural Classes I, II and III a certain amount of damage is accepted under the action of the zonal design earthquake. This damage is specified in terms of "Specified Damage Patterns". The three Specified Damage Patterns (SDP) I, II and III are described in Table 1. They cover damage to the load-bearing structure, to partitions, to facades, windows and equipment as well as requirements for continued operation of plants and for serviceability of the structure, and expenditure for repairs. Thus to each Structural Class a Specified Damage Pattern is assigned.

	SDP I	SDP II	SDP III
Load-bearing structure	high damage but without any obvious danger of collapse (withstands aftershocks of similar intensity)	medium damage (permanent deformations in many places)	low damage (with small permanent deformations in a few places)
Partitions (Non-loadbearing walls)	high damage(wide cracks, often broken parts)	fairly high damage (strongly cracked, occasionally broken parts)	unimportant damage (fine cracks)
Facades, windows, equipment (lighting, ventilation, etc.)	very large damage	substantial damage	insignificant damage (serviceability not impaired)
Continued operation of plant, serviceability of structure	not achieved but people can be evacuated	very limited	not limited
Repairs	at very high expenditure, often not possible	possible at high expenditure (cracks filled in, partition walls, windows replaced)	possible at low expenditure (cracks filled in, walls replastered)

Table 1: Specified Damage Patterns (SDP)

The Specified Damage Patterns are a great help for the classification of a certain given structure. According to the classification of the structure to the Structural Classes I, II or III, the accepted damage described by the corresponding Specified Damage Patterns I, II or III is changing. Thus the authorities, the owner and the structural engineer get a clear idea of the consequences by the classification of the structure. Additionally, the Specified Damage Patterns facilitate the assignment of important classification criteria and required verifications for structural safety and serviceability (limitation of storey drift) to the Structural Classes. Table 2, reproduced from the new code, shows this assignment.

Structural Class	Classification criteria	Specified damage (shortened version of SDP)	Required verification
I	- no large concentrations of people - no valuable goods and equipment - no danger to the environement	- high damage also to the structure but no danger of collapse	- structural safety
II	- large concentrations of people probable - valuable goods and equipment - important lifeline junction - limited (local) danger to the environment	- medium damage	- structural safety - exceptional serviceability
III	- essential lifeline junction - considerable danger to the environment	- low damage without impairment of the function	- structural safety - serviceability

Table 2: Classification of structures

DEFORMATION FACTORS ASSIGNED TO THE SPECIFIED DAMAGE PATTERNS

The expected damage in a structure depends primarily on the inelastic deformations of the load-bearing structure. This deformation is represented by the deformation factor defined as follows

$$K = \frac{\text{total overall displacement}}{\text{elastic overall displacement at yielding}} \tag{2}$$

The larger the damage the larger the deformation factor. For high damage (but no collapse) the deformation factor is equal to the wellknown overall displacement ductility factor which depends on the Structural Type. This case applies to the Specified Damage Pattern I (see Table 2). For medium or low damage, i.e. for Specified Damage Patterns II or III, the deformation factor has to be lowered according to the lower accepted inelastic deformation of the structure. Hence, the deformation factor can also be called an "accepted overall displacement ductility factor" assessed with respect to the accepted damage, i.e. with respect to the relevant Specified Damage Pattern.

Structural Type (to resist lateral forces)	SC I	SC II	SC III
Steel and Reinforced Concrete Frames	2.5	2.0	1.4
Reinforced Concrete Walls Steel Trusses	2.0	1.7	1.3
Timber Structures	1.7	1.4	1.2
Masonry Walls (unreinforced)	1.2	1.1	1.0
Beam Type Bridges (piers, girders)	-	2.5	1.5
Arch Type Bridges	-	2.2	1.4
Fixed Bearing of Bridges	-	1.0	1.0

Table 3:
Deformation factor K for eigenfrequencies $\leq$ 10 Hz for different Structural Classes (SC)

Table 3, reproduced from the new code, shows the deformation factors for the three different Structural Classes and for different Structural Types. The factors valid for Structural Class I are more or less based on a "natural" ductility resulting from a good standard of design and workmanship but not requiring many special measures to improve ductility. The factors valid for Structural Class III results from the fact that deformations should not significantly exceed elastic deformations. The factors valid for Structural Class II resulted from interpolation between Structural Classes I and III.

The deformation factors given in Table 3 are valid for structural frequencies up to 10 Hz (corner frequency of the elastic design spectra). For a structural frequency of 33 Hz or more, the deformation factor must be set equal to 1.0 due to the fact that very stiff structures do not exhibit inelastic deformations. Between 10 Hz and 33 Hz, a linear interpolation is allowed. Formula (1) shows that the deformation factor is directly used for lowering the "elastic" earthquake force given by the elastic design spectrum similar to a "behaviour factor". This wellknown procedure is based on the equal-displacement criterion and is also applied in other modern codes (e.g. [2], [3]).

In spite of the lower deformation factors of the Structural Classes II and III compared with those of Structural Class I, structures of the Structural Classes II and III must also exhibit an overall displacement ductility factor of at least the deformation factor of Structural Class I. This provides a reserve against collapse in earthquakes larger than the design earthquake for more important structures. In other codes the importance of a structure is usually taken into account by multiplying the equivalent lateral seismic force by an importance factor, which ranges from e.g. 1.0 over 1.2 to 1.4 for different structural classes [2]. The importance factor is arbitrarily fixed and one does not account for the effects on the damage pattern when the design earthquake occurs. With the procedure chosen for the new Swiss code, a completely rational calibration of the earthquake forces depending on the accepted damage described by Specified Damage Patterns is possible.

DESIGN FACTOR

The use of Specified Damage Patterns has in addition another important advantage. The resulting seismic force described above can be reduced due to the fact that the effective resistance of a structure is considerably higher than the design resistance. This difference stems mainly from the following:

- use of factile or minimum values of material strength
- use of a capacity reduction factor (or resistance factor)
- neglection of strain-hardening (steel) and time-hardening (concrete, etc.).

It turned out that the ratio between the effective resistance and the design resistance is fairly independent of the Stuctural Type and lies in the order of 1.5.

As stated above, under the action of the design earthquake the damage described in the Specified Damage Pattern is accepted. On the other hand, for the design earthquake forces the same design resistance is used as for other action forces. But for meeting the accepted damage under the design earthquake one correctly should use the effective resistance. Since this for the sake of simplicity is not opportune, a reduction of the earthquake force is obvious. This is done by the so-called design factor

$$C_d \cong \frac{1}{1.5} = 0.65 \qquad (3)$$

As a rational result of the use of Specified Damage Patterns this reduction also contributes to getting a generally acceptable level of the seismic design forces.

CONCLUSIONS

The concept of the Specified Damage Patterns proves to be an excellent tool for the calibration of the earthquake design forces for different Structural Classes. The concept allows a clear understanding of the objectives of the seismic design for authorities, owners and structural engineers and also allows by a rational way to assess the seismic design forces to a generally acceptable level in contrary to the usual concept of arbitrarily chosen importance factors.

REFERENCES

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