Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 60 (1990)

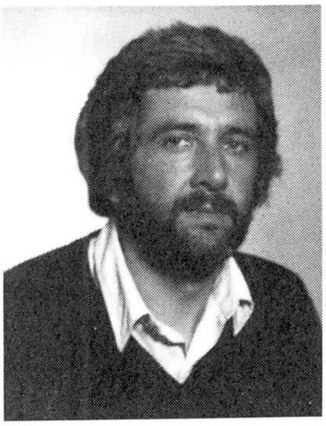
Artikel: New idea for safe structures in seismic zones
Autor: Plumier, André
DOI: https://doi.org/10.5169/seals-46518

New Idea for Safe Structures in Seismic Zones

Idée nouvelle pour la sécurité des structures en zone sismique

Neue Idee für erdbebenbeanspruchte Bauwerke

André PLUMIER
Dr. Eng.
Université de Liège
Liège, Belgium



André Plumier, born in 1947, obtained his engineer degree in 1970 at the University of Liège. He was then in charge of research on fatigue, stability and welding residual stresses. He obtained his Ph.D. in 1980. He then worked in the earthquake engineering field as a member of ECCS as a researcher and as a lecturer.

SUMMARY

Ductile structures are known to be interesting in earthquake areas, but the design criteria for the connections can be difficult and expensive to comply with. A new concept, involving creating cheap specific ductile zone close to the connections can solve this problem.

RÉSUMÉ

On connaît l'intérêt de réaliser des structures ductiles en zone sismique. Mais les critères à respecter à cette fin peuvent entraîner des difficultés technologiques et des coûts élevés des assemblages. Une idée nouvelle, consistant en la création de zones ductiles spécifiques à bon marché à proximité des assemblages, peut résoudre le problème.

ZUSAMMENFASSUNG

Die Vorteile duktiler Tragwerken in Erdbebengebieten sind bekannt. Diese Anforderungen können jedoch zu technologischen Schwierigkeiten und kostspieligen Verbindungen führen. Eine neue Idee, um dieses Problem zu lösen, besteht im Einbau kostengünstiger duktiler Bauteile nahe bei den Verbindungen.

1. INTRODUCTION

Earthquake resistant structures may be designed to resist an earthquake elastically or not.

In the latter case, the structure is designed in such a way that, during an earthquake, some parts move out of the elastic range in order to dissipate energy by means of ductile hysteretic behaviour. These parts are called dissipative zones.

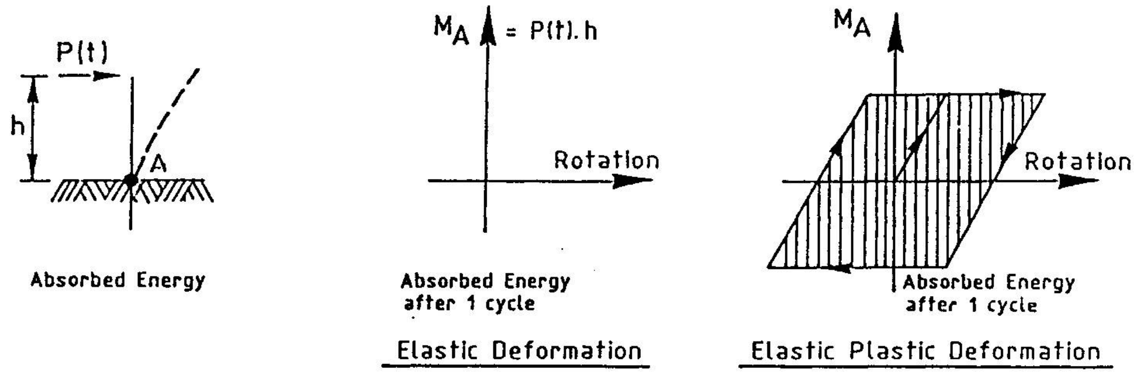


Figure 1

Figure 1 expresses the difference in absorption of energy according to the 2 concepts. As the energy input E of the earthquake is a data and as the following sum of terms

$E_e + E_d + E_y + E_{cin}$ with E_e : energy of elastic strain

E_d : energy dissipated in a visco elastic way.

E_y : energy dissipated by yielding

E_{cin} : Kinetic energy

is the only possibility to express how E is counterbalanced inside the structure, it is obvious that getting E_y as high as possible is an interesting way to absorb E. This is recognized by the fact that dissipative structures can be designed by means of a conventional elastic approach under forces reduced by a factor up to 6 when compared to non dissipative structures. This allows substantial economy on the size of the elements of the structure, but one has to pay for this economy in the form of a compliance to a certain amount of rules : rules on local behaviour are such that, locally, safe dissipative zones can exist ; rules on the shape of the structures intend to avoid local failure mechanism and to create the conditions for the formation of many dissipative zone in a structure.

2. SAFE LOCAL ENERGY DISSIPATIVE MECHANISMS AVAILABLE IN COMPOSITE STEEL CONCRETE ELEMENTS

The local energy dissipation mechanisms available to the designer in composite steel concrete elements are yielding in tension or compression ; yielding in shear and yielding in bending.

Yielding in tension is of practical interest in diagonal elements of truss bracings. Yielding in compression should there be avoided or not be relied on and replaced by means of a substitute safe mechanism based on tension diagonals only. - Figure 2 a.
Yielding in shear practically concerns the beam-colums cross zone of frames, generally called panel zone - Figure 2 b.

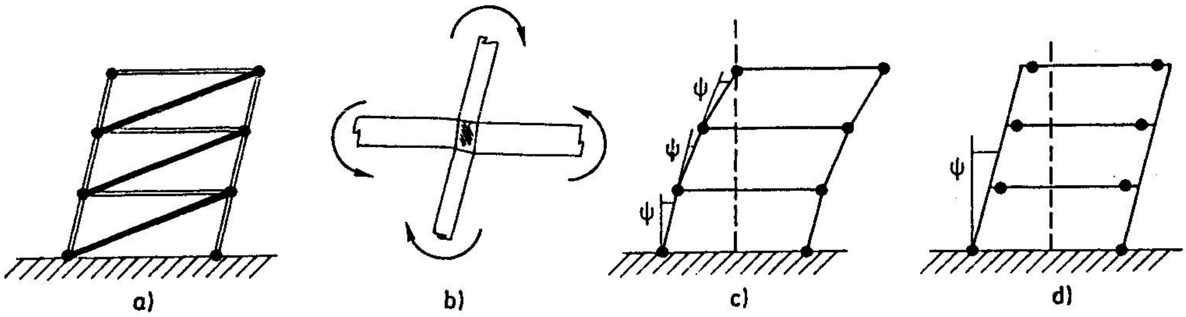


Figure 2

Yielding in bending may concern beams and columns of a frame - Figures 2 c and d. Rules on the slenderness of the compressed walls of the sections have to be complied with.
All these mechanisms may take place in composite steel-concrete elemens but concrete either in compression or in tension cannot be the place for yielding, which should be located in tension reinforcements only.
All these mechanisms should lie outside the assemblies of the elements, as the assemblies are normally not able to develop plastic mechanisms which are stable and ductile. In Eurocode 8 and in many codes around the world, this latter aim is attained by prescribing for the assemblies a resistance R_d which is superior to 120 % of the plastic resistance R_{fy} of the assembled bars according to the formula :

$$R_d \geq 1,2\ R_{fy}.$$

In the frames R_{fy} represents the plastic moments M_p of the bars. In the trusses R_{fy} is the normal plastic effort N_p of the bars.
This condition is very stringent , the assemblies resulting out of such calculations are very expensive and difficult, if not impossible, to realize, so that common practice cannot easily comply with safety requirement. The idea developed at paragraph 4 can solve this problem.

3. FACTORS FAVOURABLE TO THE PRESENCE OF MANY DISSIPATIVE ZONES

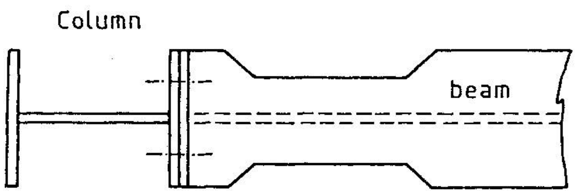
The regularity in stiffness distribution along the heigth of a structure is one classical condition to obtain many dissipative zones in a structure. But this concept is still improved if a mechanism is found which forces yielding to occur in chosen places of the deformed structure, for geometrical compatibility reasons. This is the case of the "weak beam-strong columns" concept - Figure 2 d in which columns act as spreaders of yielding through the many beams of the structure. The same concept can be applied to truss bracings : the "weak diagonals-strong columns" of Figure 3a correspond to a concept aimed at by specific requirements in Eurocode 8, for instance.

It must be pointed out that the wished regularity will only be obtained if the distribution of the real yield strengths inside the real structure does not differ too much from the distribution assumed during design. For instance, if beams delivered on site have a real yield strength f_y = 320 N/mm² instead for 235 N/mm², while in the columns f_y = 235 N/mm² as assumed in design, the plastic hinges might be located in the columns instead of the beams, changing the distribution of plastic hinges from pattern c to pattern d of Figure 2. Similarly, if some elements of the connecting parts, such as butt end plates, have the assumed yield strength while the beams or diagonals have a higher yield strength than presumed, the condition (1) is not fulfilled in reality and a brittle or little ductile failure of the connection may replace the expected good ductility of the connected elements.

These discrepancies raise practical problems : new calculations will not always be enough to avoid rejecting steel ; rejecting steel causes delay and contractual problems. The idea developed here under can again solve this problem.

4. A NEW IDEA FOR SAFE STRUCTURES IN SEISMIC ZONE

The idea developped to obtain safe structures in seismic zone is the following : dissipative zones can be "prefabricated" as such, outside the connections but close to them, by creating specific weakened zones in which yielding may take place in a safe and ductile way. This zone is formed by a reduction of the actual cross section of the profile. Examples of various possible embodiments are sketched at Figure 3. The advantage resulting from this idea, now patented, lies in the fact that condition (1) is applicable while considering the value R_{fy} of the reduced cross section of the profile.



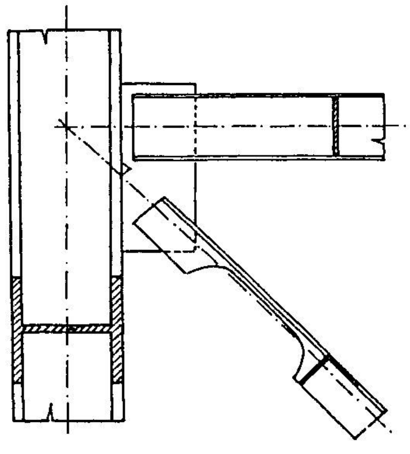


Figure 3

This allows to bring the assemblies back to dimensions comparable to those of classical projects by means of a low cost workshop operation : oxy cutting or drilling. At the same time the presence of a dissipative zone is guaranteed and it is permissible to take fully benefit from the reduction of the design loads corresponding to the seismic action, reduction which spare much more material than the eventual supplement in section resulting from a loss in rigidity. The idea can also prove its effeciency in case of troubles of the kind explained at paragraph 3 with the steel delivered on site : taking the plastic moment $M_{p\ site}$ of an overresistant element down to the design value $M_{p\ design}$ or $N_{p\ design}$ can easily be realized by oxycutting or drilling on site . The idea thus allows a strict correspondance between the intended regular structure of the design stage and the real structure achieved.

5. TEST RESULTS AND DESIGN IMPLICATIONS

Taking material out of some sections may be beneficial on the energy dissipation side and on the connection cost side. It affects the design negatively in requiring a change in the section required to make the beam or the diagonal.
A width reduction by a factor of 1,2 of the flanges results in an increase by one section (Example : HEA 260 to HEA 280) or less, depending upon the type of section and the span. For spans less than 7 m in composite steel concrete structure, some computations show that no change in section is necessary. When taking a bigger section is required, this increase in weight is compensated by a reduction by a factor of 1,2 or more of the size of the connecting elements (plates, bolts, weld).
This necessary increase in size of the element is however theoretical and related to permissible stress philosophy, for several reasons :

- consideration of the deflections does not require a higher section ;
- the real behaviour of the elements with flange width reduction by a factor of 1,20 does not give decrease in design resistance under earthquake loading ; test results given hereafter indicate a reduction by a 1,15 factor.

On Figure 4 are reported envelope curves of Moment M Rotation R diagrammes obtained under cyclic loading of exterior column connection zone of H steel sections with concrete encased between the flanges (ARBED AF system) [2][3]. It can be seen that, in spite of the width reduction in beam F2, its M-R curve is practically similar to that of the original section E3. The design resistance M_{yd} and ultimate resistance derived form the test according to ECCS testing procedure [2] are for this HEA 260 section :

	Full section E3	Reduced flanges F2
M_{yd} (kN x m)	375	325
M_v (kN x m)	420	410

Also on figure 4, it can be seen that the sheared panel mechanism in the column is locked by the concrete, inforcing all yielding to take place in the beam. This positive effect of composite construction towars composite encased column combined with flange width reduction of the beam avoids the welding of a stiffening plate on the web of the column.

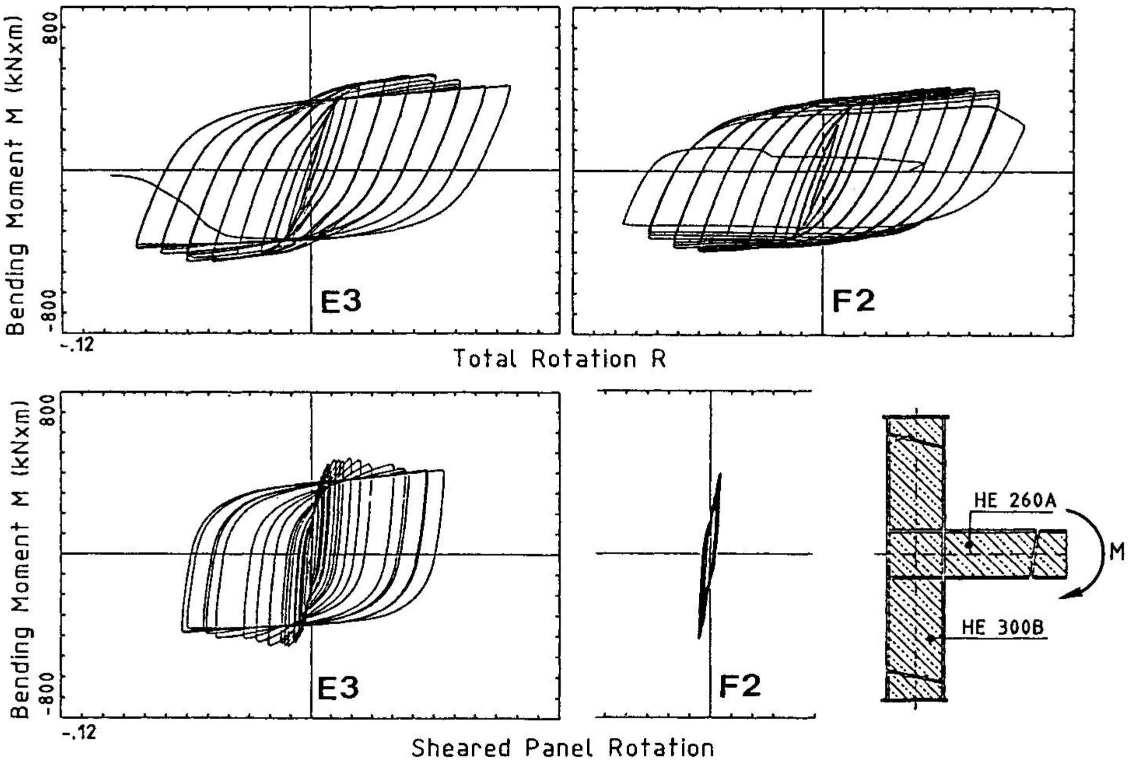


Figure 4

Test results obtained on interior columns (one column - two beams) including the presence of a slab give globally the same conclusion, with a further advantage for the application of the locally weakened section : in that case, yielding of the steel on the lower (tension) flange takes place before the crushing of the concrete of the slab against the flange of the column. It means that this new idea does not only bring more safety against collapse but also less sensitivity to damage.

7. CONCLUSION

The weakening of specific sections of a structure to change them into reliable dissipative zones in case of an earthquake is a new and simple idea. Conceptual explanations, design considerations and experimental data settle its general valididty. This now patented idea gains even more advantages in the field of composite steel-concrete structures where the concrete slab integrity can be maintained and where a steel stiffener in the web of the column can be avoided in the sheared panel zone.

BIBLIOGRAPHY

[1] Eurocode 8 - Structures in seismic regions - Design - Part 1 - May 1988. Report EUR 12266 EN - Office for official publication of the European Communities - L 2985 Luxembourg.

[2] Recommanded testing procedure for assessing the behaviour of structural steel elements under cyclic loads. European Convention for Constructional Steel work n°45 - 1986.

[3] Seismic resistance of Composite structures - ARBED - CEC Research 7210 - SA/506 Technical Report 3 - ARBED Recherches RPS. BP141 - L 4002 ESCH/ALZETTE.