

# “INERD”

**Title:** INERD – Two INnovations for Earthquake Resistant Design

**Fund:** Research Fund for Coal and Steel (Contract number 7210-PR-316)

**Partners:** Université de Liege (Univ-Liege), Instituto Superior Technico "IST" (Lisbon), National Technical University of Athens (NTUA), Politecnico di Milano (Politec Milano), Profilarbéd (PROFILARBED), Università Degli Studi di Trento (UNIV TRENTO).

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**Research group (NTUA):** P. Thanopoulos

**Duration:** 1/7/2001 – 30/6/2004




## Summary

The project develops research work about two innovations. The first innovation consists in promoting one specific construction measure by which the so called "soft storey" mechanism is obviated in the lower storeys of reinforced concrete (R.C.) frames by encasing steel profiles in the R.C. columns in order to provide them with a basic reliable shear, bending and compression resistance. Tests are performed and comparison of the behaviour of reference reinforced concrete specimens and innovative composite specimens are made. Several parameters are studied, like axial load, length of anchorage, stiffeners in the panel zone, weak and strong axis bending, configurations with and without infills. The study results in the definition of practical rules for the design of steel profiles to be encased in ductile R.C. columns, tentative formulas for the behaviour of local strut and tie mechanism in case of configurations with infills and formulas for the calculation of the shear resistance of a composite beam-to-column panel zone in case of configurations without infills.

The second innovation consists in using connections of diagonals of frames with concentric bracing as dissipative elements. Two selected types of dissipative connections are studied: the so-called pin connections, made of bent rounded or rectangular stocky bars, and the so-called U-device connection, made of flexible U bent plates. The behaviour of both connections has been experimentally, analytically and numerically studied on individual connection specimens and on frame specimens. Fatigue curves have been obtained for the connections. Practical design rules have been defined for frames containing the INERD connections, especially for the pin connection. Case studies of realistic buildings are presented.


## Publications


### **Journals:**

1. Vayas I. and Thanopoulos P.: Innovative dissipative (INERD) pin connections for seismic resistant braced frames, International journal of steel structures, vol. 5, no. 5, p. 453 – 463, 2005. 
2. Vayas I. and Thanopoulos P.: Dissipative (INERD) Verbindungen für Stahltragwerke in Erdbebengebieten, Stahlbau 75, Heft 12, Ernst & Son, 2006. 
3. Vayas I., Thanopoulos P. and Castiglioni C.: Stabilitätsverhalten von Stahlgeschossbauten mit dissipativen INERD-Verbindungen unter Erdbebenbeanspruchung, Bauingenieur 82, März 2007. 


### **International conferences:**

1. Vayas I., Calado L., Castiglioni C. A., Plumier A. and Thanopoulos P.: Innovative dissipative (INERD) connections for seismic resistant steel frames, Proceedings of 3rd International Symposium on Steel Structures, 10-11 March 2005, Seoul, Korea, 2005.
2. Vayas I., Thanopoulos P., Plumier A., Castiglioni C. A. and Calado L.: Behaviour of seismic resistant braced frames with innovative dissipative (INERD) connections, Proceedings of the 4th European conference on steel and composite structures, 8-10 June 2005, Maastricht, The Netherlands, Hoffmeister B. and Hechler O. eds., volume C, p. 5.2-25 – 5.2-32, Druck and Verlaghaus Mainz,

Germany, 2005. 

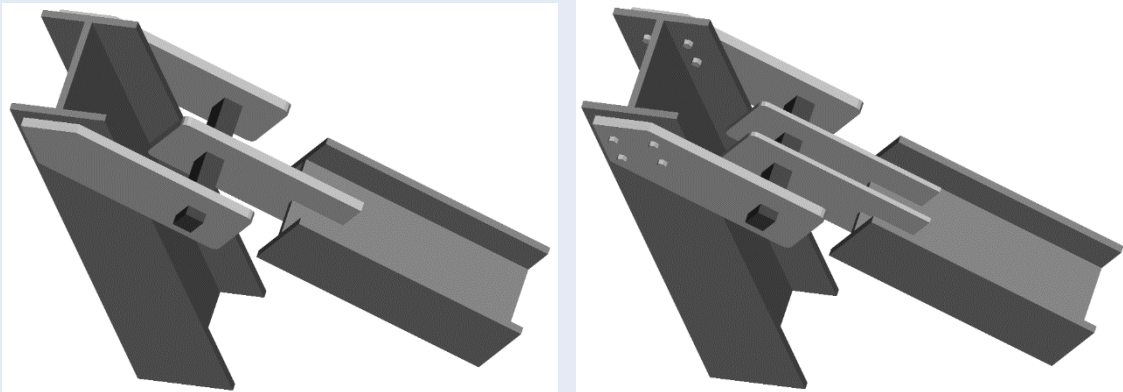
3. Vayas I. and Thanopoulos P.: Seismic resistant braced frames with dissipative (INERD) connections, Proceedings of the 5th conference on Behaviour of steel structures in seismic areas (STESSA), Yokohama, Japan, 2006, Mazzolani and Wada eds., p. 801 – 806, Taylor & Francis Group, London. 

#### Technical reports:

1. Plumier A., Doneux C., Castiglioni C., Brescianini J., Crespi A., Dell' Anna S., Lazzarotto L., Calado L., Ferreira J., Feligioni S., Bursi O. S., Ferrario F., Somnavilla M., Vayas I., Thanopoulos P. and Demarco T.: Two Innovations for Earthquake Resistant Design – The INERD Project – Final Report, Research Programme of the Research Fund for Coal and Steel: Steel RTD, Report EUR 22044EN, 2006. 

### Description of the INERD pin connection

The INERD pin connections are used in frames with concentric braces to connect the braces with the adjacent members. The pin connections are dissipative and partial-strength compared to the brace, so that energy can be dissipated within the connections, while the braces and other members of the frame are protected from buckling and yielding. The INERD pin consists of two external plates which are connected to the column or beam, and one or two internal plates which are connected to brace. A pin, which can have a rectangular, rounded or circular cross section, passes through all the plates via appropriate-sized holes.

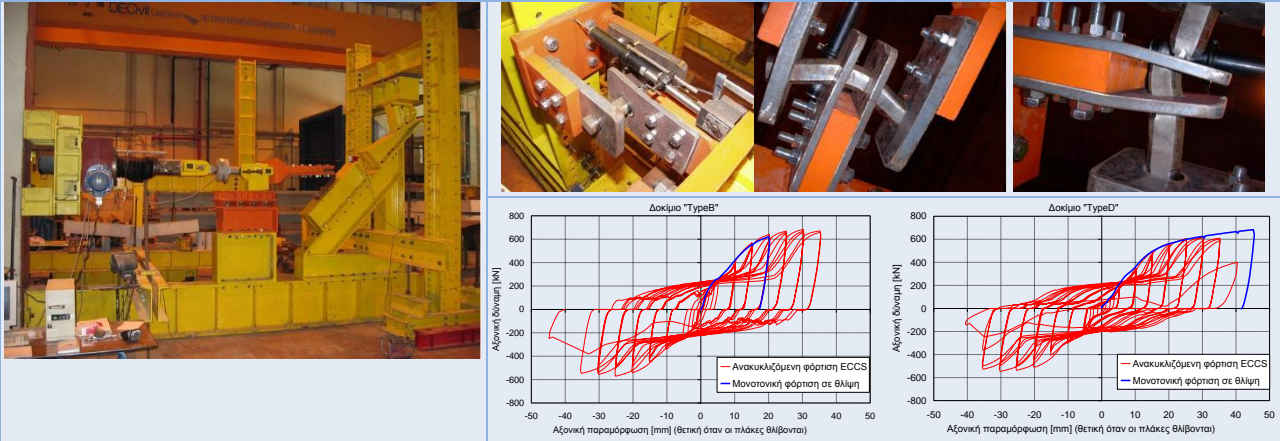


## Experimental investigations

Tests of the INERD project that were related to the pin connections:

### 1. Tests on individual connections (IST Lisbon)

- 20 specimens
- Monotonic loading (4), cyclic loading according to ECCS (4) and constant amplitude cyclic loading (12)



### 2. Tests on full-scale frames (Politecnico di Milano)

- 8 specimens
- Cyclic loading according to ECCS (4) and cyclic loading from a seismic event (4)





## Numerical and analytical investigations

- Processing of experimental results
- Analytical investigation and development of a simplified analytical model (Fig. 1)
- Development and calibration of FE models based on experimental results (Fig. 2, 3)
- Extensive parametric analysis with FE models (Fig. 4)
- Development of detailed analytical model and a design guide for practical applications (Fig. 5)
- Nonlinear static and incremental dynamic analyses of 2D frames (Fig. 6, 7). Investigation of global behaviour and residual drifts. Comparison between CBF and frames with INERD pin connections. Evaluation of behaviour factor for seismic design.

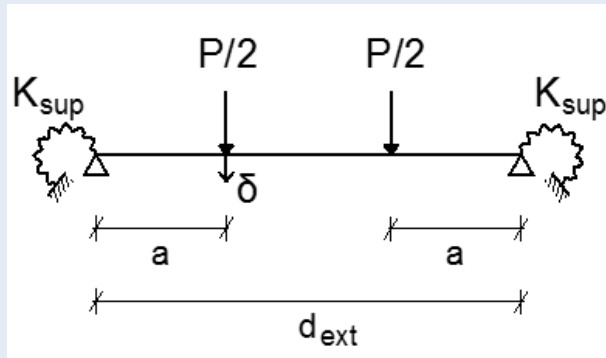


Fig. 1: Simplified analytical model

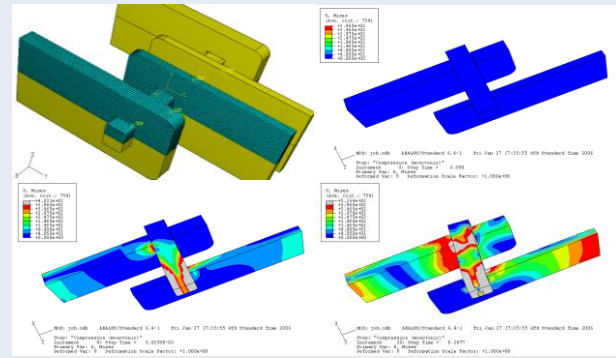


Fig. 2: Finite Element Model

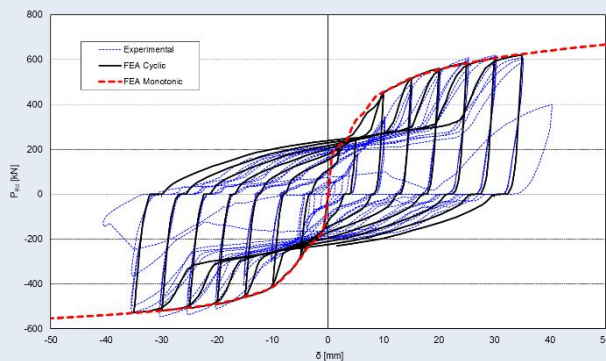


Fig. 3: Calibration between tests and FEA results

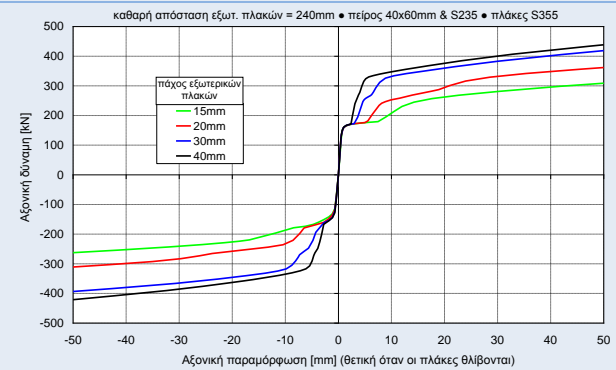


Fig. 4: Indicative results from parametric FEA

	Πλάκες σε	Χαρακτηριστική τιμή αντοχής
Σημείο I Διαρροή "γ"	Θλίψη	$P_{y,Rk} = \frac{1}{1,05} \cdot \min \left\{ \frac{2 \cdot M_{d-pl}}{a_{rd,j}} ; k_{pm} \cdot \frac{2 \cdot M_{pl}}{a} \right\}$
Σημείο III Αστοχία "u"		$a_{rd,III} \leq 0 \Rightarrow P_{u,Rk} = \frac{k_{pm}}{1,10} \cdot 2 \cdot b \cdot h \cdot f_y / \sqrt{3}$
		$a_{rd,III} > 0 \Rightarrow P_{u,Rk} = \frac{k_{pm}}{1,10} \cdot \frac{4 \cdot M_u}{a_{rd,III}} = \frac{k_{pm}}{1,10} \cdot \frac{2 \cdot b \cdot (1 - 2 \cdot \beta_m) \cdot h \cdot f_y}{\sqrt{3}}$
Σημεία I και III	Εφελκυσμό	90% των τιμών $P_{y,Rk}$ και $P_{u,Rk}$ για θλίψη
Συντελεστές ασφάλειας		$\gamma_{M0} = 1,0$ μειωτικός συντελεστής για τον υπολογισμό της αντοχής $\gamma_{cap} = 1,3$ συντελεστής υπεραντοχής, για τον ικανοτικό σχεδιασμό
		Αξονική παραμόρφωση διαρροής: $\delta_y = 1,5 \cdot \frac{M_{d-pl}}{E \cdot I} \cdot l^2 \cdot \frac{a}{6} \cdot (3 - 4\alpha)$ Ικανότητα αξονικής παραμόρφωσης: $\delta_{lim} = 0,8 \cdot a$

Fig. 5: Design guide

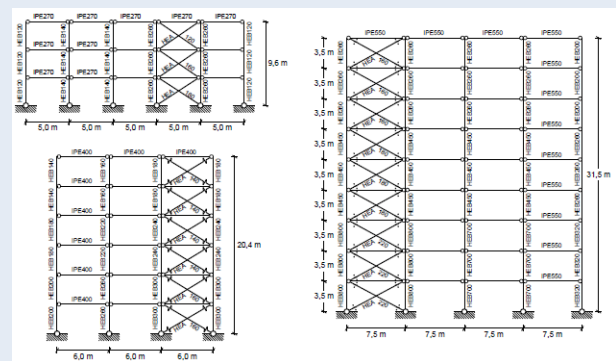


Fig. 6: Views of 2D frames under investigation

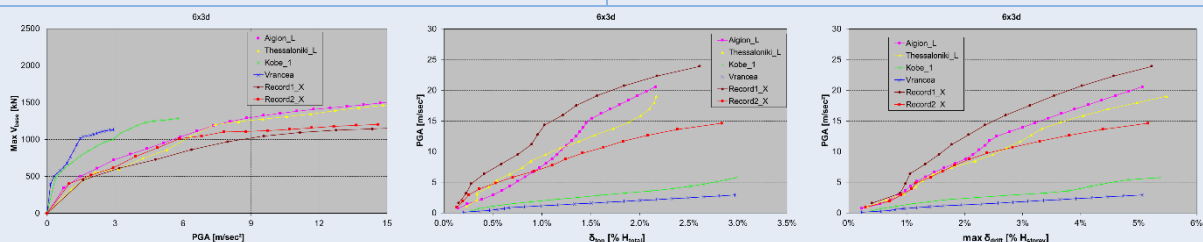


Fig. 7: Base shear, total and interstorey drifts for increasing PGA (6-storey frame with INERD pins)