STRUCTURAL ANALYSIS PORTFOLIO

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Abstract

The presented document presents a selection of numerical models which I carefully validated by comparing the results either to experimental or analytically-derived ones.

Reviews

Rev.00 – July 2023

INTRODUCTION

Preface

Since a large number of mechanisms of resistance control the behaviour/strength of structural concrete, it is important to validate NLFEA (Note. Non-Linear-Finite-Element-Analysis) programs for the type of behaviour anticipated in the structure being designed or analyzed. This is best achieved by the development of a database of personally conducted and well-documented model calibration and validation efforts on a suite of NFLEA programs. Over time, the user will develop a measure of the strengths and limitations of each NLFEA program and develop appropriate global safety factors for each program. (FIB. Bulletin 45 - Practitioners' Guide to Finite Element Modelling of Reinforced Concrete Structures. Vol 1. Lausanne, Lausanne, Swizzerland; 2008. doi:10.1017/CBO9781107415324.004)

The presented document was mainly inspired by the previous statement which, although it refers specifically to non-linear-finite-element-analysis of reinforced-concrete structures, I believe applies generally to numerical structural analysis. In this regard, I briefly present a selection of numerical models which I carefully validated by comparing the results either to experimental or analytically-derived ones.

Reinforced concrete (RC) structures are the ones which I addressed the most because they represented my core business during my PhD and Post-Doc period at Politecnico di Milano. Nevertheless, I tried increase my general confidence level in numerical models by addressing other structural problems when there was the chance, e.g. preparation of practices for MS courses at the University, freelance jobs, spare time.

Either global (load-to-displacement curves) or local (stress-to-strain) results were used in validating numerical models. Frequently experimental results are given only for the former. Further, because the lack of accuracy numerically-derived stresses (strains) with respect to displacements and reactions (see Payen DJ, Bathe KJ. The use of nodal point forces to improve element stresses. *Comput Struct*. 2011;89(5-6):485-495. doi:10.1016/j.compstruc.2010.12.002), the effort to validate a numerical model based on local response is generally large.

Of course, validation of a model is not an immediate outcome. Most of the presented results were obtained after several hours of trials-and-errors. Those hours, according to my opinion, increased my level of confidence in modelling much more than any perfect match obtained in comparing numerical results to experimental ones.

Plan of the Document

The document has different sections mainly based on the type of element used such ase frame, plane, shell, brick. Each model is presented in a single page form in which the both main characteristics and results are given along with some comments on the model's peculiarity. The terminology used throughout the document is summarized in the next page. For the sake of clarity, the Reader is invited to refer to the colour version of this document.

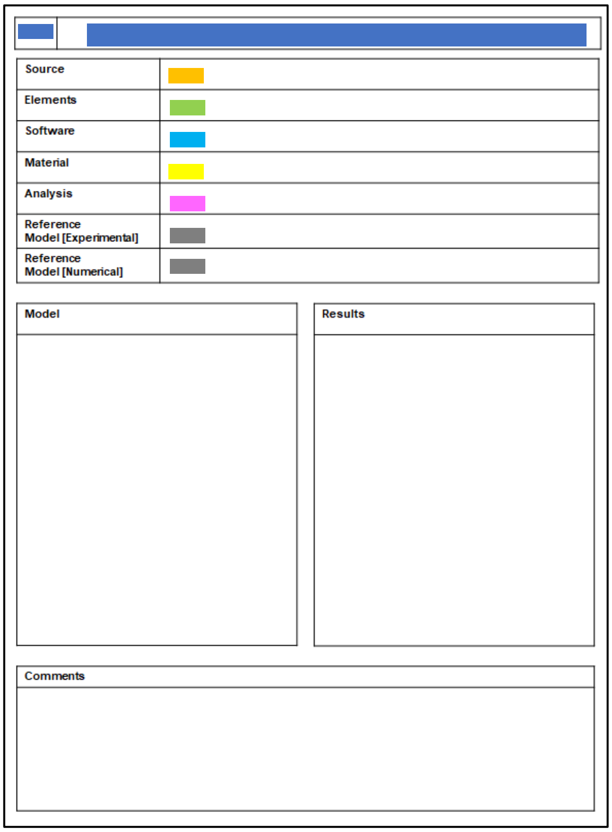
Acknowledgements

Most of the structural analysis were developed during my research work carried out at Politecnico di Milano where I took advantage of the availability of academic licenses for structural analysis software, such as SAP-2000, STRAUS-7, ATENA, R-FEM.

Additionally, for RC structures I used profoundly software developed by E. Bentz at University of Toronto (see https://www.hadrianworks.com/) which are freely distributed. Besides, I developed a FEM solver (using plate elements) for the column's base plate which is going to be embedded (at the date a testing version has been relased) in calculation software for metal fasteners.

Finally, either experimental or numerical results used for comparison were retrieved from publications which I have surveyed. In many cases, results were digitally-re-derived by using GetDataDigitizer software.

FORM AND TERMINOLOGY



Reference is made to the available experimental results used for comparison with respect to the numerical model. NA, Not-Applicable.

Reference is made to the available numerical results used for comparison with respect to the numerical model. NA, Not-Applicable.

SECTION	TITLE

[Personal Archive]: The analysis was carried out either for research or professional job, results are not public.
[Published]: Results were published. Reference to the publication is given.

[FRAME]: Linear element with 2 nodes and 12 dofs.
[2D PLANE STRESS]: Quadrilateral elements with 4 nodes and 8 dofs. Occassionally, refined to 8 nodes and 16 dofs.
[3D BRICK]: Hexagonal elements with 8 nodes and 16 dofs.
[PLATE]: Quadrilateral elements with 4 nodes and 12 dofs.
[SHELL]: Quadrilateral elements with 4 nodes and 20 dofs.

[SAP2000]: CSI. CSI Analysis Reference Manual. For SAP2000, ETABS, SAFE, CsiBridge [Version 2017].; 2017.
[ATENA]: Cervenka V, Jendele L, Cervenka J. ATENA Program Documentation Part 1 Theory. Atena. 2012:1-282.
[RFEM]: Dlubal. Rfem 5 - User Manual. 2016;(February):590.
[STRAUS 7]: Strand7. Using Strand7/Straus7. Introduction to the Strand/Straus7 Finite Element Analysis System. 2010. www.strand7.com.
[RESPONSE/MEMBRANE-2000]: 1. Bentz EC. Sectional analysis of reinforced concrete members. 2000. https://hdl.handle.net/1807/13811.
[FLEXIBLE BASE PLATE]: Developed by A. Marchisella as freelance. The software solves through FEM analysis, using PLATE elements, column's base plate attached to concrete foundation via fasteners. Technical documentation is available upon request.
[OPEN SEES]: McKenna F. OpenSees: A framework for earthquake engineering simulation. Comput Sci Eng. 2011;13(4):58-66. doi:10.1109/MCSE.2011.66
[Stated otherwise].

[Linear Elastic]: Characterized by Young's Moduls and Poisson Ratio.
[Non-Linear Concrete (MCFT)]: Cervenka V, Jendele L, Cervenka J. ATENA Program Documentation Part 1 Theory. Atena. 2012:1-282.
[Non-Linear Concrete (PLAS)]: Chen WF. Plasticity in Reinforced Concrete. J. Ross Publishing; 2007.
[Non-Linear Steel]: Unless otherwise stated, elasto-plastic + hardening is assumed.
[Non-Linear Spring]: Analytically-derived Force-to-Displacemenent constitutive law.

[Linear Static]
[Non-Linear Static]{Max absolute residual error 10^{-2}}
[Non-Linear Quasi-Static] {Max absolute residual error 10^{-2}}
[Modal Response Spectrum]
[Linear Time-History]
[Non-Linear Time History] {Max absolute residual error 10^{-2}}
[Buckling]

FRAME and MULTI-SPRINGS

FRA	**PRESTRESSING ANCHORAGES**

Source	Personal Archive
Elements	FRAME(Truss)
Software	SAP2000
Material	Linear-Elastic
Analysis	Linear-Static
Reference Model [Experimental]	NA
Reference Model [Numerical]	Collins MP, Mitchell D. Prestressed Concrete Structures. Englewood Cliffs: Prentice-Hall International; 1991.

Model

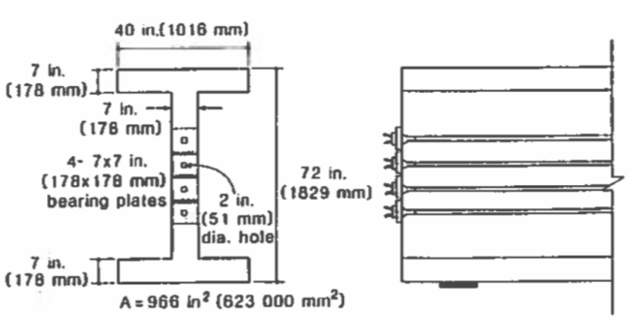
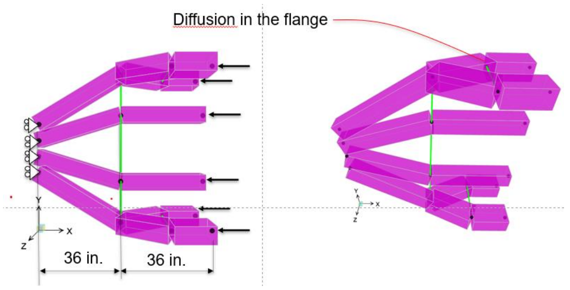


Figure 9-26 Details of anchorage region in post-tensioned I-beam.

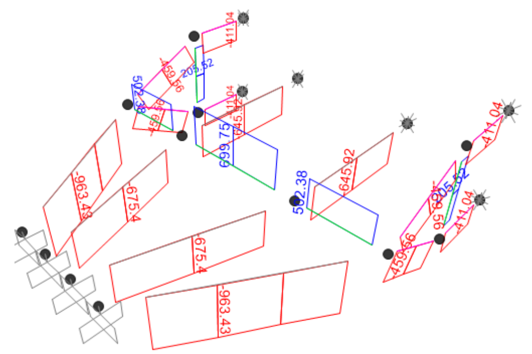


Results

Strut and Tie model (After Cracking)

Str. Analysis

Segm.	Pos.	Collins (kN)	AM (kN)	diff (-)
CD	web	564	502	-0.109
DE	web	774	700	-0.096
GH	flange	175	206	0.174



Comments

The numerical investigation addressed anchorage zone of prestressed girder. Such diffusion zone (state of stress is not easy to derive) is analyzed using Strut-And-Tie approach. In this context concrete struts and reinforcement ties are introduced in an equivalent truss model. Axial forces derived from numerical model were compared with respect the values given in the reference.

FRA	PRESTRESSED REDUNDANT BEAM

Source	Personal Archive
Elements	FRAME / TENDONS
Software	SAP2000
Material	Linear-Elastic
Analysis	Linear-Static
Reference Model [Experimental]	NA
Reference Model [Numerical]	Collins MP, Mitchell D. Prestressed Concrete Structures. Englewood Cliffs: Prentice-Hall International; 1991.

Model

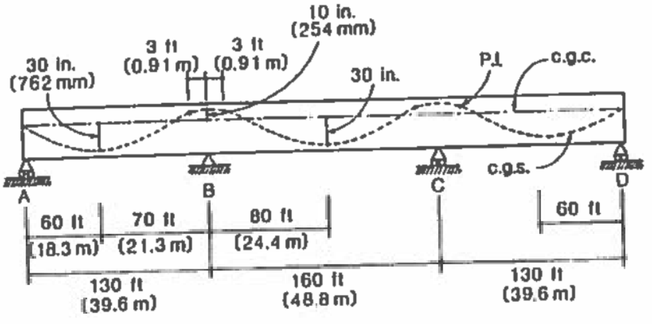
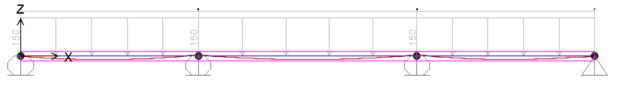


Figure 10-24 Three-span, post-tensioned bridge.



Results

	Moment due to Redundancy		
SPAN	S2000 (kN·m)	Collins (kN·m)	Err. (-)
A-B	10707	10699	-0.001
B-C	10707	10699	-0.001

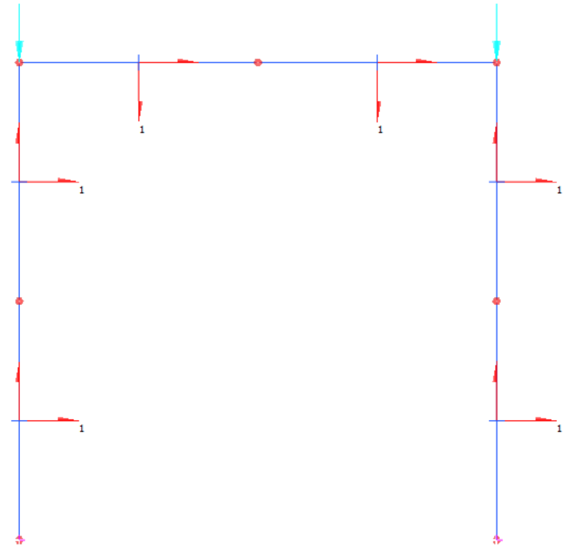
Comments

The numerical investigation addressed redundant prestressed girder. Parabolic tendon element are used. Redundant bending moments in nodes B and C are compared with respect to values given in the reference.

FRA	BUCKLING - FRAME

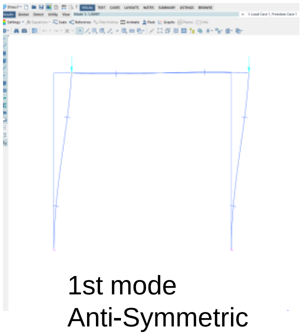
Source	Personal Archive
Elements	FRAME
Software	STRAUS-7
Material	Linear-Elastic
Analysis	Buckling
Reference Model [Experimental]	NA
Reference Model [Numerical]	Bleich F. Buckling Strength of Metal Structures. New York: McGraw-Hill; 1952. / 1. Corradi Dell'Acqua L. Meccanica Delle Strutture (Vol. 3) - La Valutazione Della Capacità Portante. Milano: McGraw-Hill; 1994.

Model

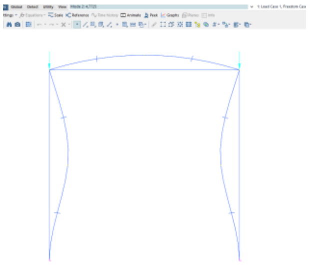


Results

Esempio Corradi Paragrafo 17.3							
Portale Piano 3000x3000, sezione 100x100							
Condition	**LELE**	**pa**			**ps**		
	(mm)	**Bleich**	**Corradi**	**FEM**	**Bleich**	**Corradi**	**FEM**
HINGED	3000	1.826	1.837	1.825	12.890	12.689	16.870
HINGED	1500	1.826	1.837	1.821	12.890	12.689	13.014
HINGED	750	1.826	1.837	1.820	12.890	12.689	12.903
CLAMPED	3000	7.382	7.447	7.441	25.167	25.379	44.999
CLAMPED	1500	7.382	7.447	7.398	25.167	25.379	25.772
CLAMPED	750	7.382	7.447	7.377	25.167	25.379	25.247



1st mode
Anti-Symmetric



2nd mode
Symmetric

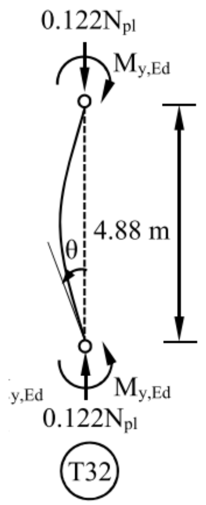
Comments

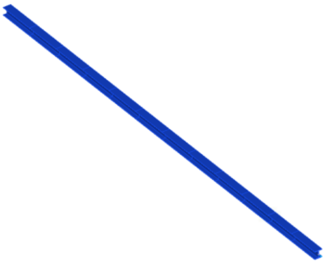
The buckling multipliers numerically-obtained for the first and second buckling modes are compared with respect to analitically-derived ones. The effect of mesh refinement in the accurancy of the seceond buckling multiplier was evident.

FRA | VAN KUREN's Beam (FLEXURAL-TORSIONAL BUCKLING)

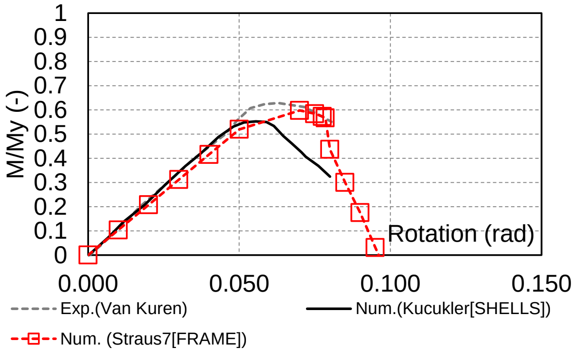
Source	Personal Archive
Elements	FRAME
Software	Straus-7
Material	Non-Linear (Elasto-Plastic [Von-Mises])
Analysis	Non-Linear (Material+Geometry)
Reference Model [Experimental]	Reported by Kucukler M, Gardner L, Macorini L. Flexural-torsional buckling assessment of steel beam-columns through a stiffness reduction method. *Eng Struct*. 2015;101:662-676. doi:10.1016/j.engstruct.2015.07.041
Reference Model [Numerical]	Kucukler M, Gardner L, Macorini L. Flexural-torsional buckling assessment of steel beam-columns through a stiffness reduction method. *Eng Struct*. 2015;101:662-676. doi:10.1016/j.engstruct.2015.07.041

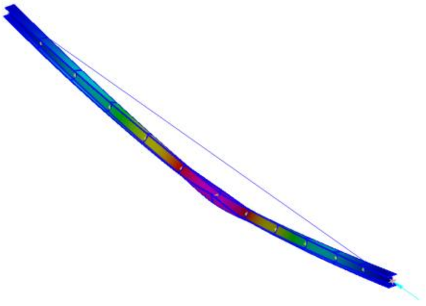
Model





Results





Comments

The numerical investigation addressed a steel beam under compression and uniform bending moment. Such condition was adopted experimentally to promote flexural-torsional buckling. Although selection of frame elements might be dubious in case of flexural-torsional buckling (compared to shells) a refinement was made by considering a dense subdivision of the cross-section to allow spread of both material and geometrical non-linearities. Agreement was found with respect to experimental results.

FRA | OH's PRESTRESSED BEAM

Source	Personal Archive
Elements	FRAME
Software	RESPONSE2000
Material	Non-Linear Concrete(MCFT) / Non-Linear Steel (Rebar, Tendons)
Analysis	Non-Linear Static
Reference Model [Experimental]	Oh BH, Kim KS. Shear Behavior of Full-Scale Post-Tensioned Prestressed Concrete Bridge Girders. ACI Struct J. 2004;101(2):176-182. doi:10.14359/13014
Reference Model [Numerical]	NA

Model

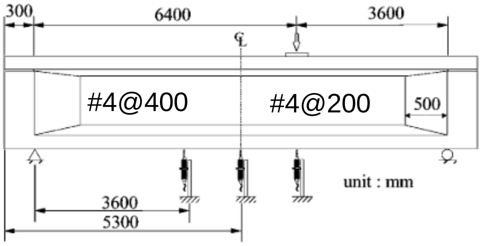
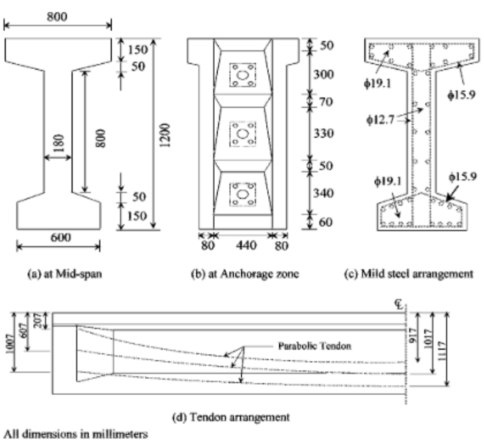
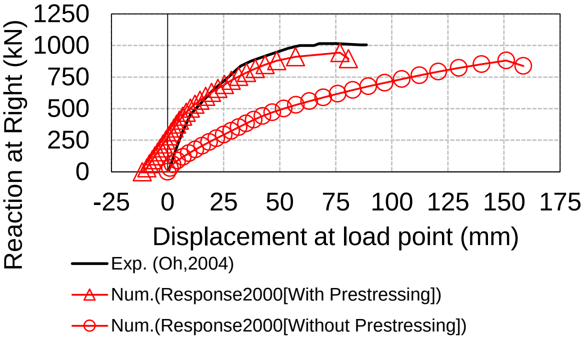
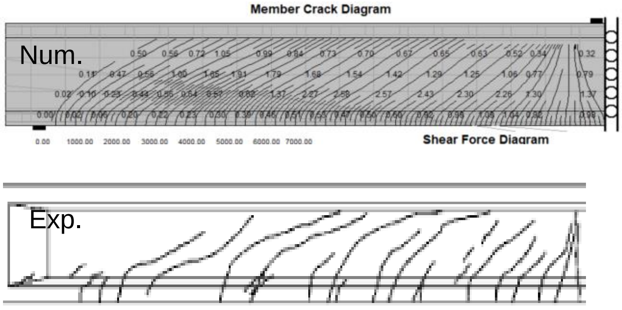


Fig. 1—Dimensions of test girder and loading arrangement.



Results





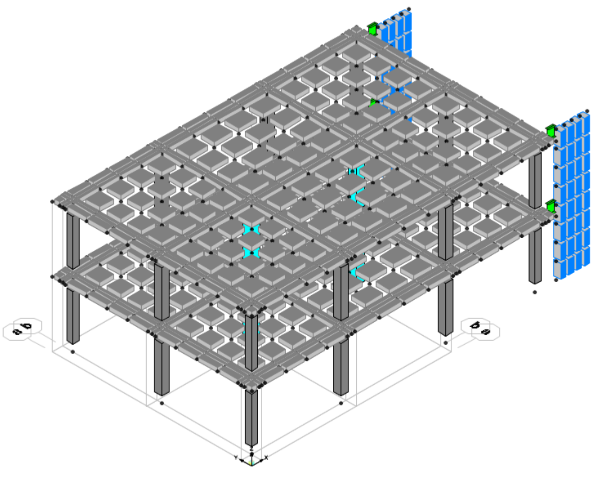
Comments

The numerical investigation addressed a prestressed beam under three-point bending test. The scope was to investigate the effect of prestressing in both load-carrying capacity and mode of failure. Results show that when prestressing is activated flexural failure is attained. Whereas shear failure is obtained without prestressing although comparable load-carrying capacities are numerically obtained. Finally agreement was found with respect to experimental results (with activated prestressing) apart from pre-camber effect at initial prestressing which was not measured during the experiments.

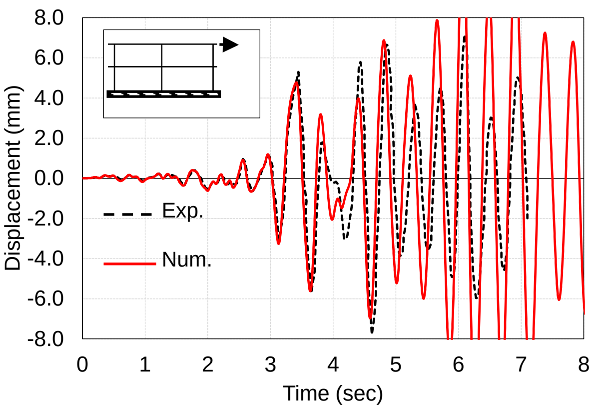
FRA	SLAB STRESS TEST

Source	Personal Archive
Elements	FRAME/SHELLS
Software	SAP2000
Material	Linear Elastic
Analysis	Linear Time History
Reference Model [Experimental]	Coronelli D, Lamperti Tornaghi M, Martinelli L, et al. Testing of a full-scale flat slab building for gravity and lateral loads. Eng Struct. 2021;243(May):112551. doi:10.1016/j.engstruct.2021.112551
Reference Model [Numerical]	NA

Model



Results



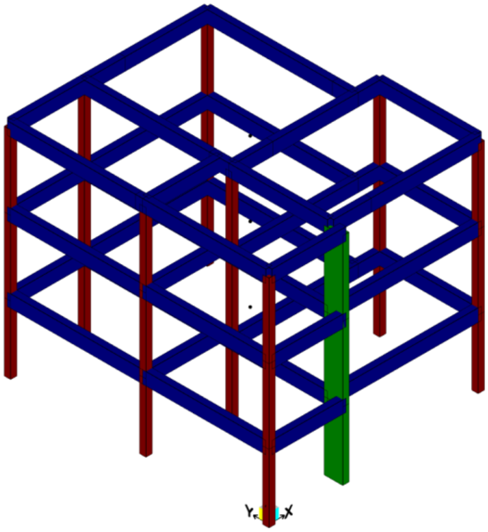
Comments

The numerical investigation addressed a RC frame (flat slab type designed as secondary system) tested pseudo-dynamically. The test had the peculiarity of the adoption of two fictitious shear walls (numerically simulated during the test). Experimental behavior showed almost linear-elastic response without any evidence of damage under the application of a scaled earthquake time-history, thus linear-elastic material was assumed. The scope was to investigate the reliability of simple slab-to-column connections, i.e. only one node is shared. Although the dynamic period of the structure was comparable with respect to numerical results numerical displacements diverges most probably due to lack of accuracy on damping modeling.

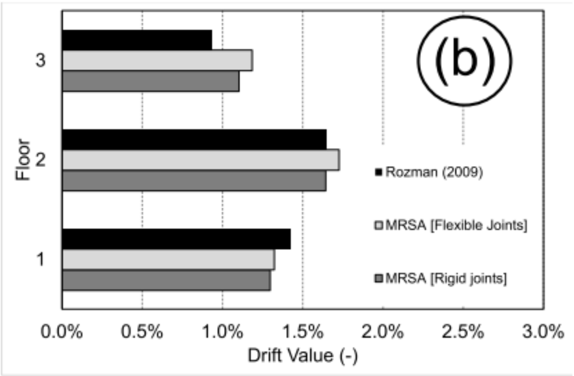
FRA	**SPEAR - MRSA**

Source	Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153
Elements	FRAME
Software	SAP2000
Material	Lumped Plasticity
Analysis	Modal Response Spectrum
Reference Model [Experimental]	Negro P, Mola E, Molina FJ, Magonette GE. Full-scale PsD testing of a torsionally unbalanced three-storey non-seismic RC frame. In: 13th World Conference on Earthquake Engineering. Vancouver; 2004.
Reference Model [Numerical]	Rozman M, Fajfar P. Seismic response of a RC frame building designed according to old and modern practices. Bull Earthq Eng. 2009;7(3):779-799. doi:10.1007/s10518-009-9119-4

Model



Results



Author/Model	Ref.	T_1 (s)	M_X (%)	M_Y (%)	T_2 (s)	M_X (%)	M_Y (%)	T_3 (s)	M_X (%)	M_Y (%)
DiLudovico	[27]	0.62	71.80	5.80	0.54	12.40	60.50	0.43	12.40	60.50
Reynouard	[21]	0.64	-	-	0.54	-	-	0.42	-	-
Stratan	[36]	0.57	-	-	0.48	-	-	0.39	-	-
Rozman	[34]	0.80	69.00	4.80	0.69	15.60	47.80	0.58	2.70	30.30
Negro (Experimental)	[19]	0.84	-	-	0.78	-	-	0.67	-	-
RIGID	This paper	0.85	55.00	0.00	0.47	2.18	56.00	0.35	31.00	27.00
FLEXI	This paper	1.24	54.00	0.00	0.64	2.10	56.00	0.50	31.00	27.00

Notes. M_X and M_Y are the participating masses in X and Y direction, respectively.

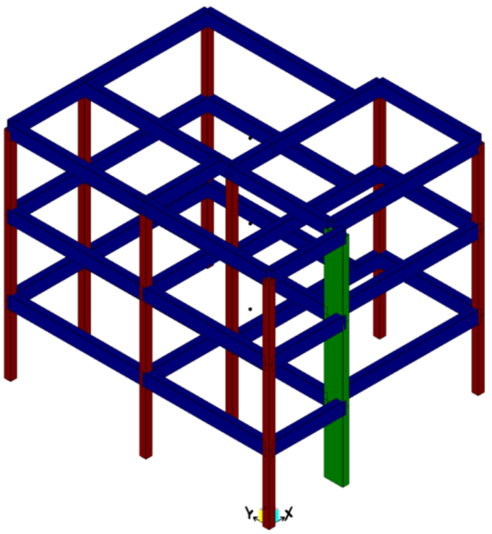
Comments

See Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153.

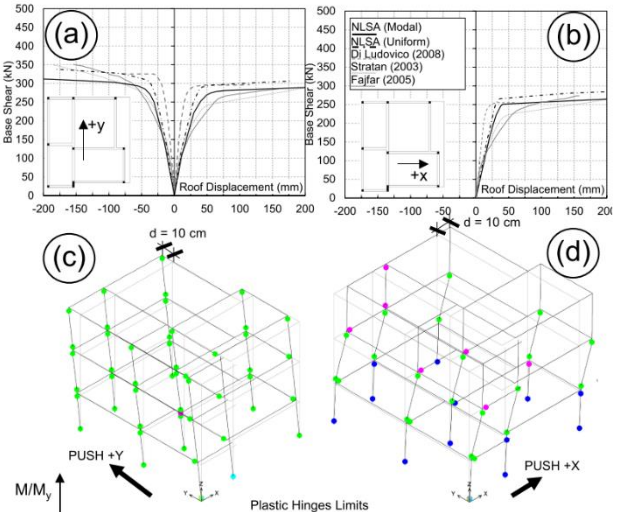
SPEAR - NLSA

Source	Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153
Elements	FRAME
Software	SAP2000
Material	Lumped Plasticity
Analysis	Non-linear Static
Reference Model [Experimental]	NA
Reference Model [Numerical]	Stratan A, Fajfar P. Influence of Modelling Assumptions and Analysis Procedure on the Seismic Evaluation of Reinforced Concrete GLD Frames. Lubjana; 2002.

Model



Results



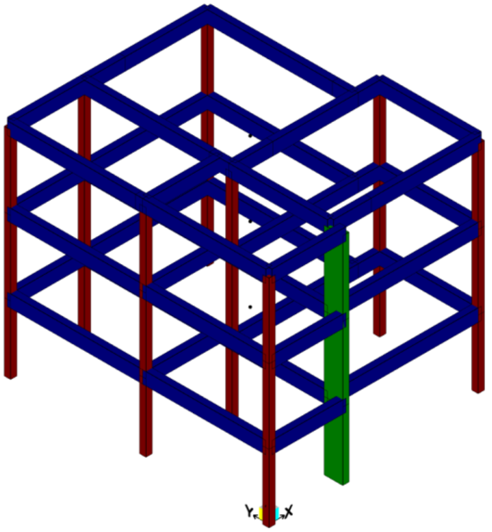
Comments

See Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153

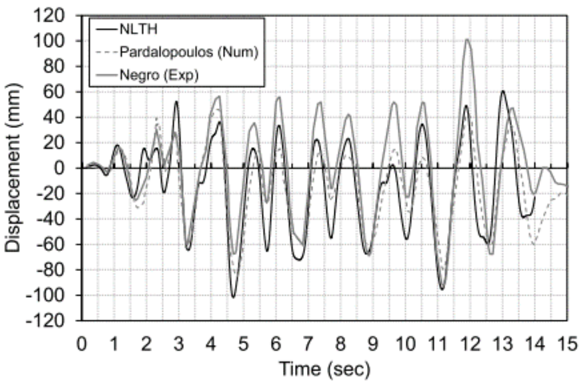
FRA	**SPEAR - NLTH**

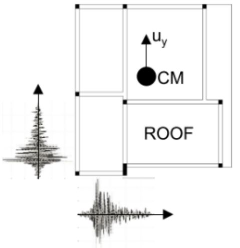
Source	Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153
Elements	FRAME
Software	SAP2000
Material	Lumped Plasticity
Analysis	Non-linear Time History
Reference Model [Experimental]	Negro P, Mola E, Molina FJ, Magonette GE. Full-scale PsD testing of a torsionally unbalanced three-storey non-seismic RC frame. In: 13th World Conference on Earthquake Engineering. Vancouver; 2004.
Reference Model [Numerical]	Pardalopoulos SI, Pantazopoulou S, Manolis GD. On the Modeling and Analysis of Brittle Failure in Existing RC Structures Due to Seismic Loads. Appl Sci. 2022.

Model



Results





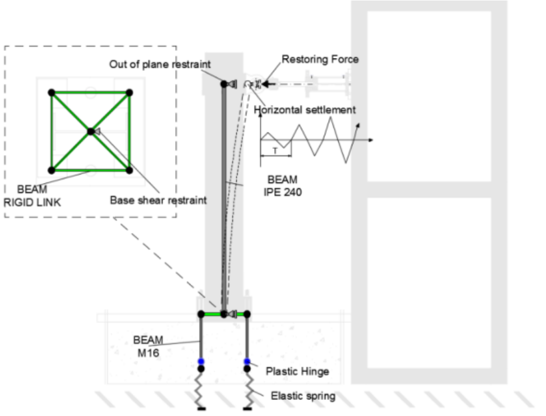
Comments

See Marchisella A, Muciaccia G. Comparative Assessment of Shear Demand for RC Beam-Column Joints under Earthquake Loading. Appl Sci. 2022;(12). doi:10.3390/ app12147153.

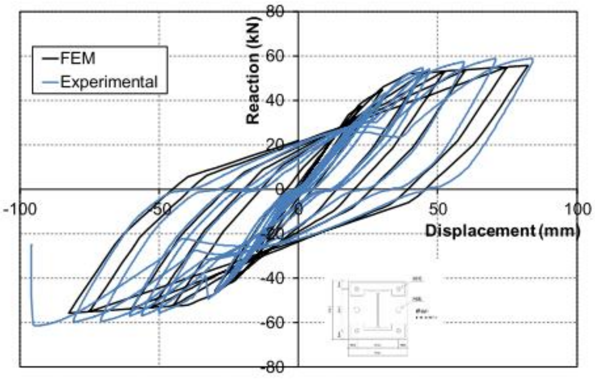
FRA	COLUMN-TO-FOUNDATION with PI FASTENERS

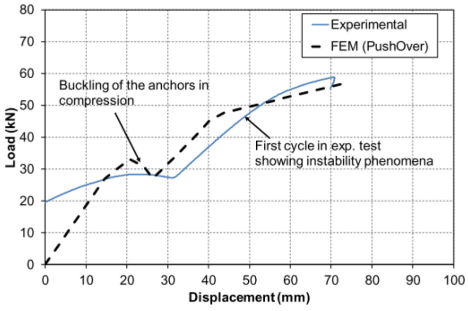
Source	Marchisella A, Muciaccia G. Numerical Investigation of Dissipative Behavior of Connection Using Post-Installed Anchors. In: *16th European Conference on Earthquake Engineering*. ; 2018:1-12.
Elements	FRAME / SPRINGS
Software	SAP2000
Material	Linear-Elasitic steel for beam/ Non-Linear springs for anchors
Analysis	Non-Linear Quasi-Static
Reference Model [Experimental]	Muciaccia G. Behavior of post-installed fastening under seismic action. ACI J. 2017;February:1-34.
Reference Model [Numerical]	

Model



Results





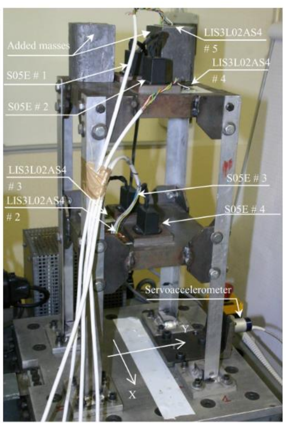
Comments

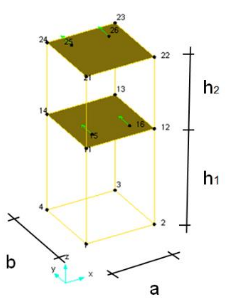
The numerical investigation addressed a steel-to-concrete connection (column-to-foundation). The peculiarity of the connection is the adoption of stretch length for anchor to promote ductile mechanical response under uni-axial bending. Lumped plasticity was used to model the anchors. Agreement between numerical and experimental results was found with respect to hysteretic behavior however a thorough understanding of buckling phenomena occurred during experiments was possible by means of additional pushover analysis.

FRA	**FDD applied to SIMPLE FRAME**

Source	Personal Archive
Elements	FRAME
Software	SAP2000
Material	Linear-Elastic
Analysis	Modal
Reference Model [Experimental]	Martinelli L, Gentile C. System identification and monitoring by using low-cost MEMS sensors. In: PAPI 15. ; 2015:123-132.
Reference Model [Numerical]	Martinelli L, Gentile C. System identification and monitoring by using low-cost MEMS sensors. In: PAPI 15. ; 2015:123-132.

Model

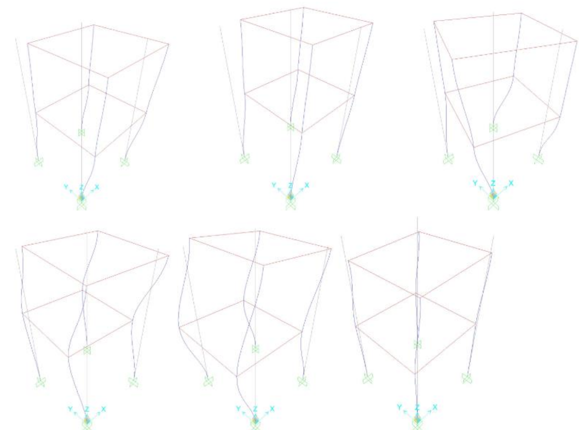




Results

MODE	SAP2000 (Hz)[a]	Direction[b]	FDD - Sweep (Hz)[c]	FDD - Impulse[d]
I	28.30	yy	26.37	26.85
II	39.96	xx	39.06	39.55
III	73.40	zz	75.19	76.17
IV	102.98	yy	104.49	105.957
V	140.21	xx	-	-
VI	211.59	z + zz	-	211.26

[a] Natural frequencies obtained via modal analysis (SAP2000)
[b] Direction of the modal shapes obtained via modal analysis (SAP2000)
[c] Peak-picking via FDD method in case of sweep loading
[d] Peak-picking via FDD method in case of impulse loading



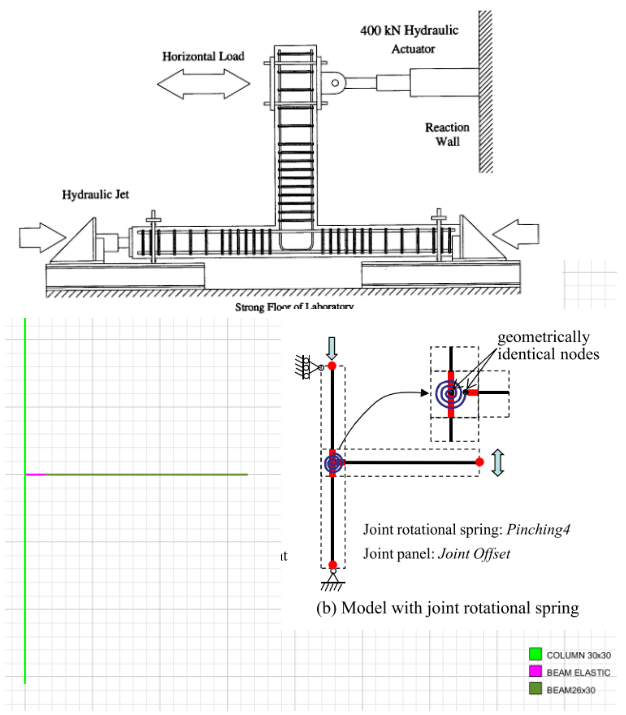
Comments

The numerical investigation addressed a scaled frame (two-storyes, 1 bay) tested under sweep and impulse excitation. Experimental time signals recorded via accelerometers (courtesy of L. Martinelli) were analyzed using Frequency Domain Decomposition (FDD, implemented in MatLab). Natural frequencies and modal shapes were numerically-derive from numerical model and finally compared to experimentally-derived ones.

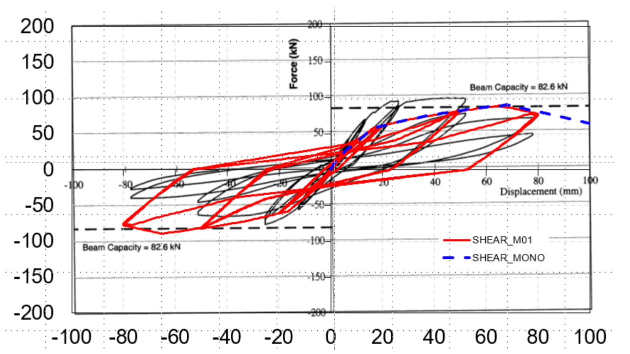
FRA	WONG's RC BEAM-COLUMN JOINTS

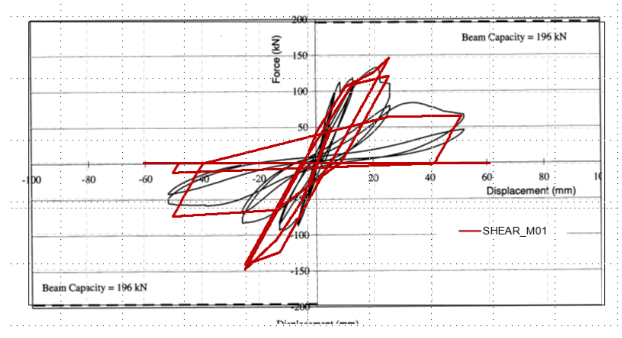
Source	Personal Archive
Elements	FRAME / SPRINGS
Software	OPEN SEES
Material	Non-linear equivalent spring for joint / Fiber sections for beam
Analysis	Non-Linear
Reference Model [Experimental]	Wong HF. Shear Strength And Seismic Performance of Non-Seismically Designed Reinforced Concrete Beam-Column Joint. 2005. doi:10.14711/thesis-b914043
Reference Model [Numerical]	NA

Model



Results





Comments

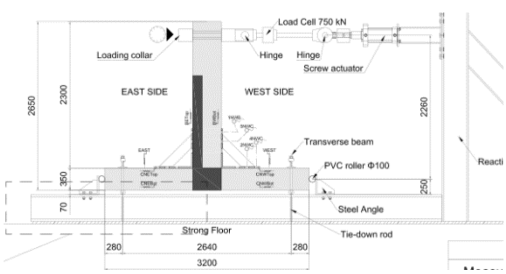
The numerical investigation addressed a shear critical beam-column joint. The non-linear backbone assigned to the joint panel was analytically-derived from Park S, Mosalam KM. Simulation of reinforced concrete frames with nonductile beam-column joints. *Earthq Spectra*. 2013;29(1):233-257. doi:10.1193/1.4000100. Hysteresis model according to «Pinching-4» (see https://opensees.berkeley.edu/wiki/index.php/Pinching4_Material) was able to reproduce the intermediate un-loading path quite well.

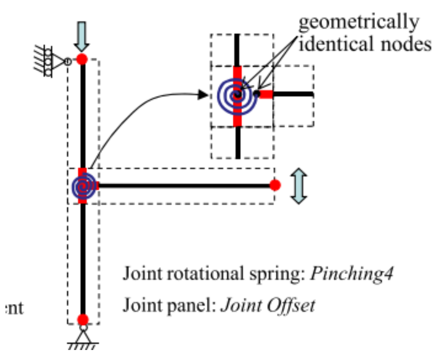
FRA

MARCHISELLA's RC BEAM-COLUMN JOINTS

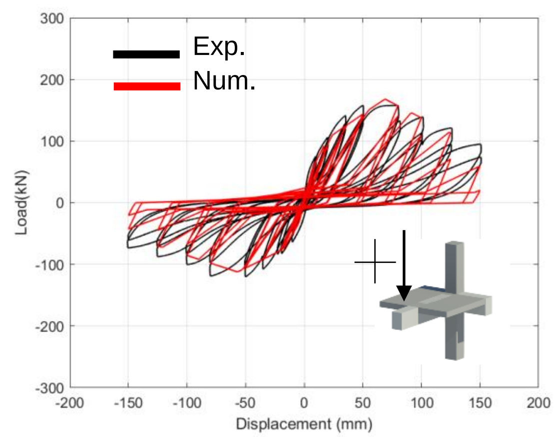
Source	Personal Archive
Elements	FRAME / SPRINGS
Software	OPEN SEES
Material	Non-linear equivalent spring for joint / Fiber sections for beam
Analysis	Non-Linear Quasi Static
Reference Model [Experimental]	Marchisella A, Muciaccia G, Sharma A, Eligehausen R. Experimental investigation of 3d RC exterior joint retrofitted with FFHR. Eng Struct. 2021;239(July):112206. doi:10.1016/j.engstruct.2021.112206
Reference Model [Numerical]	Tonidis M, Sharma A. Numerical investigations on the influence of transverse beams and slab on the seismic behavior of substandard beam-column joints. Eng Struct. 2021;247(September):113123. doi:10.1016/j.engstruct.2021.113123

Model





Results



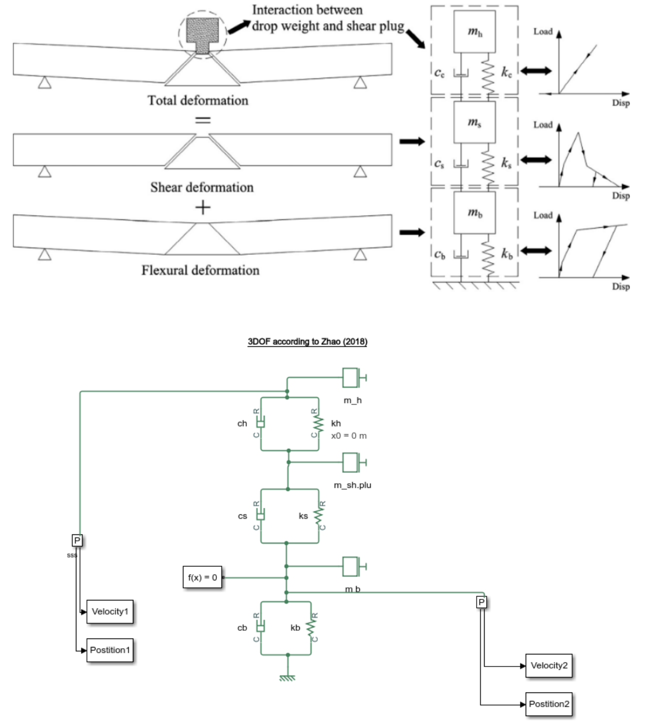
Comments

The numerical investigation addressed a shear critical beam-column joint with slab and transverse beam. The non-linear backbone assigned to the joint panel was analytically-derived from Park S, Mosalam KM. Simulation of reinforced concrete frames with nonductile beam-column joints. *Earthq Spectra*. 2013;29(1):233-257. doi:10.1193/1.4000100. Hysteresis model according to «Pinching-4» (see https://opensees.berkeley.edu/wiki/index.php/Pinching4_Material) was able to reproduce the intermediate un-loading path quite well.

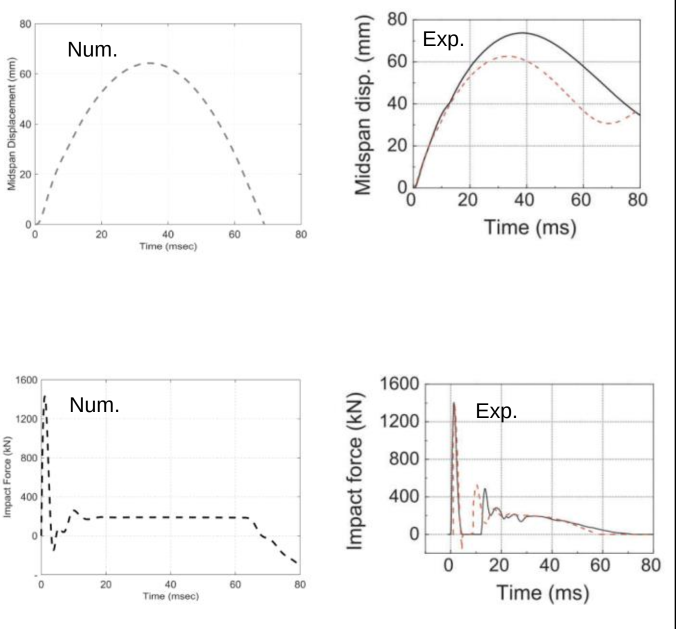
FRA	**ZHAO's RC BEAM under IMPACT**

Source	Personal Archive
Elements	SPRINGS
Software	SIMSCAPE (see Matworks. Simscape User Guide. 2018.)
Material	Non-linear equivalent spring for beam under impact
Analysis	Non-Linear Time History
Reference Model [Experimental]	Zhao D-B, Kunnath SK. Simplified Approach for Assessing Shear Resistance of Reinforced Concrete Beams under Impact Loads. ACI Struct J. 2016;113(4). doi:10.14359/51688617
Reference Model [Numerical]	NA

Model



Results



Comments

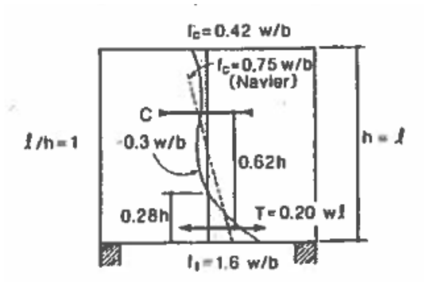
The numerical investigation addressed RC beam under impact (drop-weight test). An analytical model, retrieved from technical literature, composed by a series of springs, dashpots and lumped masses was implemented in Simscape. Agreement was found for the comparison of both deflection and impact force.

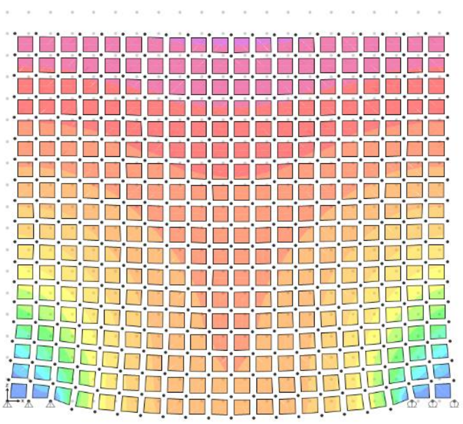
2D PLANE

2DP LEONHARDT's DEEP BEAM

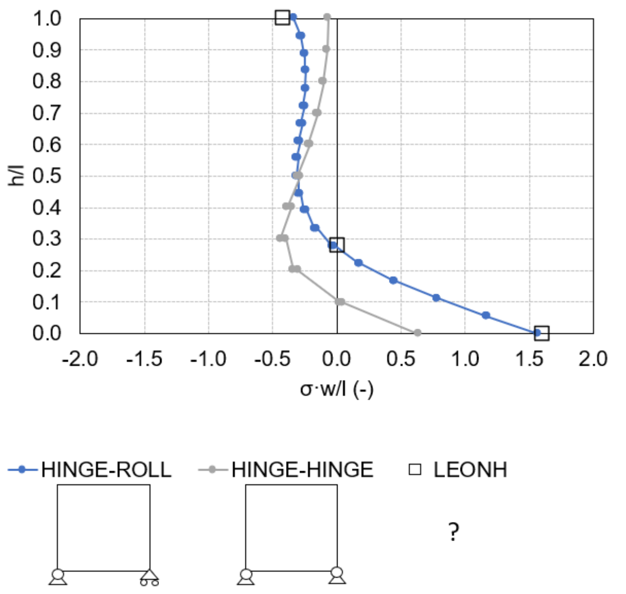
Source	Personal Archive
Elements	2D plane stress
Software	SAP 2000
Material	Linear Elastic
Analysis	Linear Static
Reference Model [Experimental]	NA
Reference Model [Numerical]	Collins MP, Mitchell D. Prestressed Concrete Structures. Englewood Cliffs: Prentice-Hall International; 1991.

Model





Results



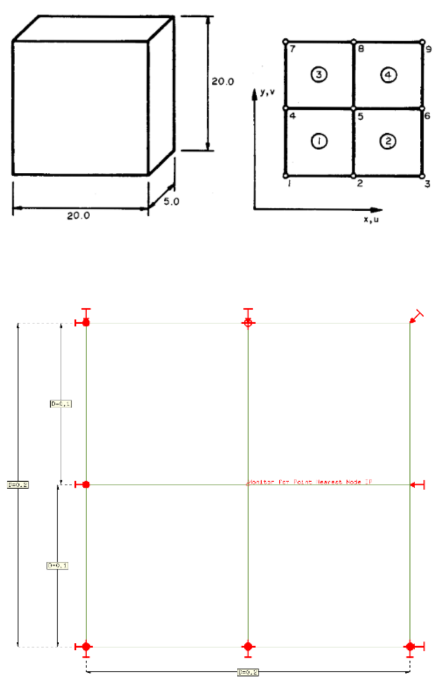
Comments

The numerical investigation addressed the problem of a deep beam having the height of the cross-section equal to the span. Scopes of the numerical investigations were two: (i) define the restraint conditions (which were not clearly stated in the reference document) and (ii) evaluate the accuracy of numerically-derived stresses. For the latter, comparison was given with respect to analytically-derived stresses.

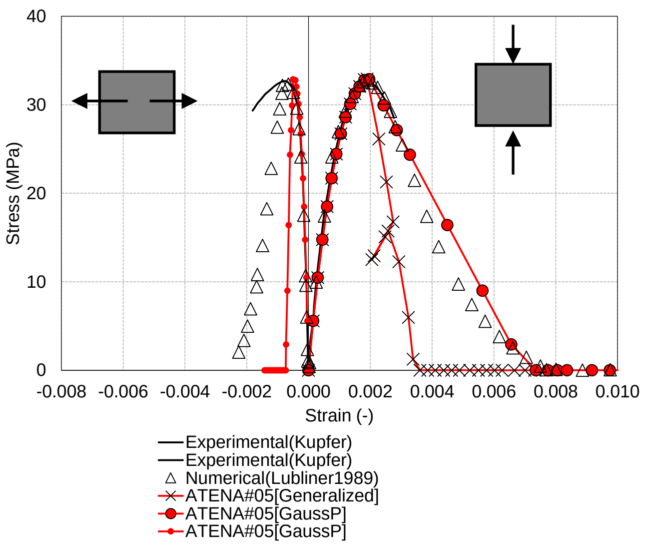
2DP	KUPFER's PATCH TEST

Source	Personal Archive
Elements	2D plane stress
Software	ATENA
Material	Non-Linear Concrete (MCFT)
Analysis	Non-Linear Static
Reference Model [Experimental]	Kupfer H, Hilsdorf H. Behavior of Concrete Under Biaxial Stresses. ACI J Proc. 1969;(66):656-666.
Reference Model [Numerical]	Lubliner J, Oliver J, Oller S, Oñate E. A plastic-damage model for concrete. Int J Solids Struct. 1989;25(3):299-326. doi:10.1016/0020-7683(89)90050-4

Model



Results



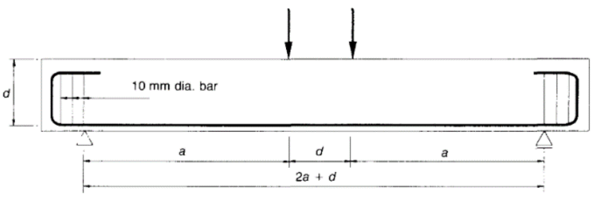
Comments

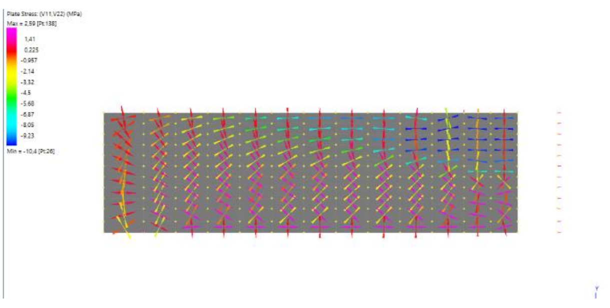
The numerical investigation adressed square block of plain concrete under pure compression. The scope of the investigation was to evaluate the performance of non-linear model of concrete implemented in ATENA software. Agreement was found with respect to experimental and numerically-derived independent results. Differences in numerically-derived stresses between gauss points and nodes (after average) were recognized.

2DP KIM's RC SHEAR CRITICAL BEAM

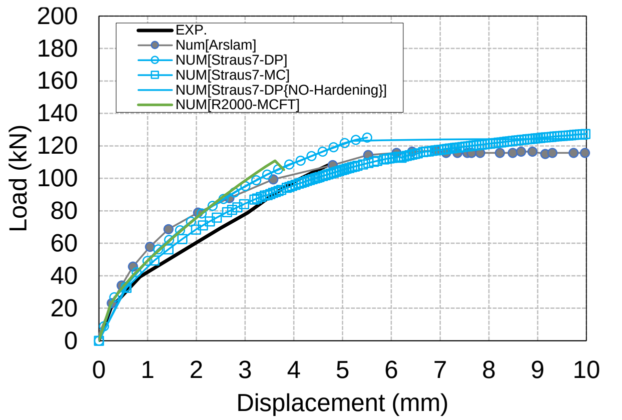
Source	Personal Archive
Elements	2D Plane Stress
Software	STRAUS-7 / RESPONSE 2000
Material	Non-Linear Concrete (PLAST) / Non-Linear Steel reinforcement (perfect bond)
Analysis	Non-Linear Static
Reference Model [Experimental]	Kim J-K, Park Y-D. Shear strength of reinforced high strength concrete beams without web reinforcement. Mag Concr Res. 1994;46(166):7-16. doi:10.1680/macr.1994.46.166.7
Reference Model [Numerical]	Arslan G. Sensitivity study of the Drucker-Prager modeling parameters in the prediction of the nonlinear response of reinforced concrete structures. Mater Des. 2007;28(10):2596-2603. doi:10.1016/j.matdes.2006.10.021

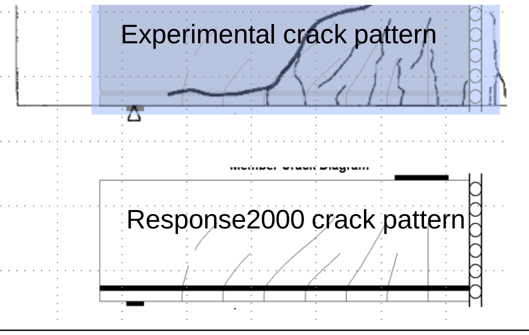
Model





Results





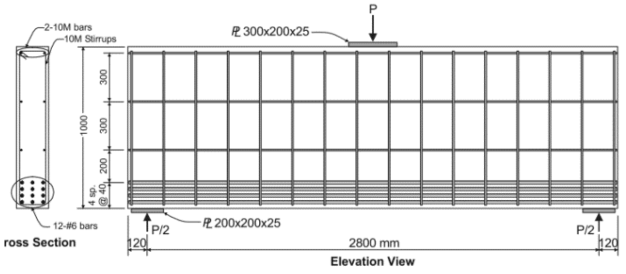
Comments

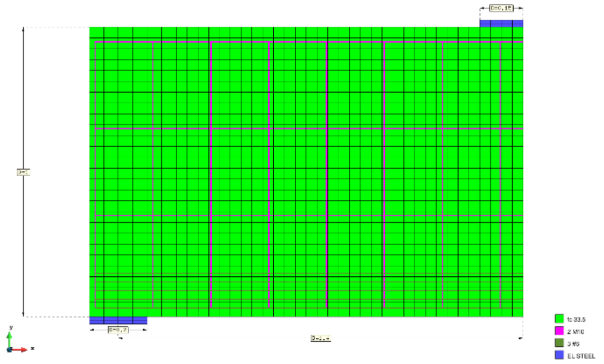
The scope of the investigation was to evaluate the performance non-linear model of concrete implemented in STRAUS-7 software, based on plasticity theory (e.g. Mhor-Coulomb type). The selected benchmark was a shear-critical RC beam. Numerically-derived load-carrying capacity was in agreement with respect to both experimental results and numerically-derived ones using Response-2000. Displacement field cannot be compared conclusively because lack of kinematic description intrinsic to plasticity models.

LEE's RC DEEP BEAM

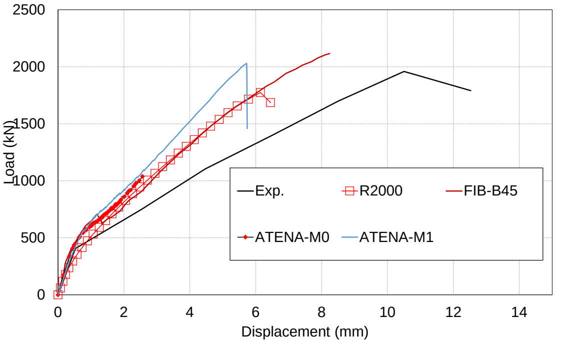
Source	Personal Archive
Elements	2D Plane stress
Software	ATENA / RESPONSE 2000
Material	Non-Linear concrete (MCFT) / Non-Linear steel reinforcement (perfect bond)
Analysis	Non-Linear static
Reference Model [Experimental]	FIB. Bulletin 45 - Practitioners' Guide to Finite Element Modelling of Reinforced Concrete Structures. Vol 1. Lausanne, Lausanne, Swizzerland; 2008. doi:10.1017/CBO9781107415324.004
Reference Model [Numerical]	FIB. Bulletin 45 - Practitioners' Guide to Finite Element Modelling of Reinforced Concrete Structures. Vol 1. Lausanne, Lausanne, Swizzerland; 2008. doi:10.1017/CBO9781107415324.004

Model

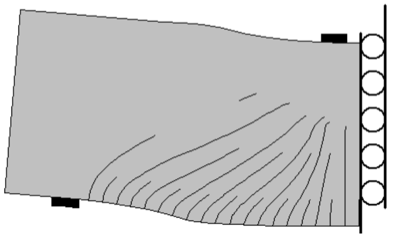




Results



Member Crack Diagram



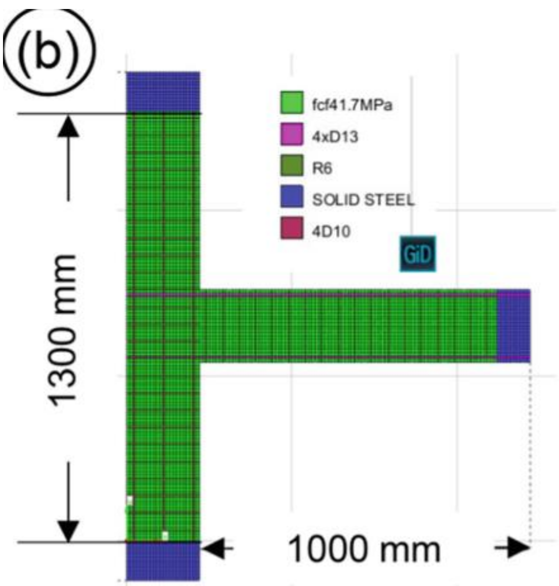
Comments

The scope of the investigation was to evaluate the performance non-linear model of concrete implemented in ATENA software, based on MCFT. The selected benchmark was a shear-critical RC beam. Numerically-derived load-carrying capacity was in agreement with respect to both experimental results and numerically-derived ones using Response-2000. Besides, comparison is made to numerical results included in the reference document, i.e. FIB-B45 curves in the figure. Displacement field cannot be compared conclusively.

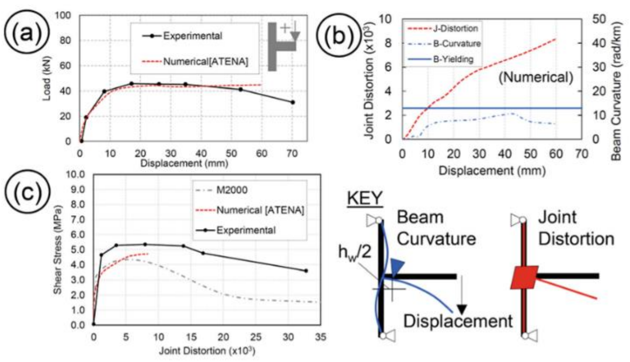
2DP	KAKU's SPECIMEN

Source	Marchisella A, Muciaccia G. RC Beam-Column Joints as Membrane Elements: An Application of MCFT. In: Fib SYMPOSIUM: International Symposium of the International Federation for Structural Concrete. Springer Nature Switzerland; 2023:509--519. doi:10.1007/978-3-031-32511-3_54
Elements	2D plane stress
Software	ATENA / MEMBRANE 2000
Material	Non-linear concrete (smeared crack) / Non-Linear steel reinforcement (perfect bond)
Analysis	Non-linear Static
Reference Model [Experimental]	Kaku T, Asakusa H. Bond and anchorage of bars in reinforced concrete beam-column joints. ACI Spec Publ. 1991;123:401-424.
Reference Model [Numerical]	NA

Model



Results



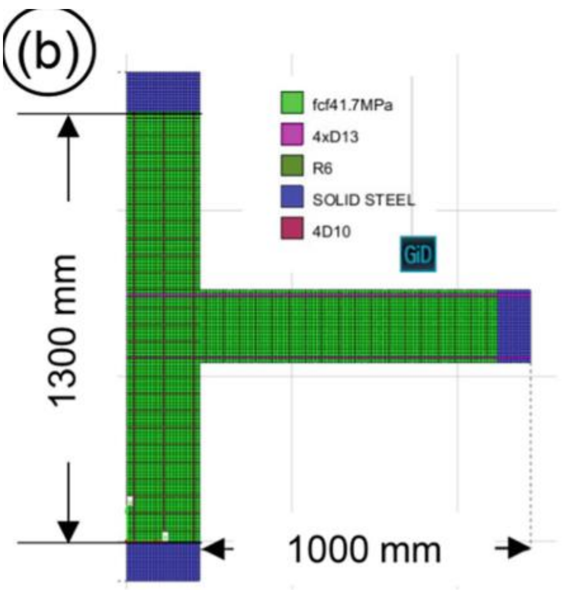
Comments

See Marchisella A, Muciaccia G. RC Beam-Column Joints as Membrane Elements: An Application of MCFT. In: Fib SYMPOSIUM: International Symposium of the International Federation for Structural Concrete. Springer Nature Switzerland; 2023:509--519. doi:10.1007/978-3-031-32511-3_54.

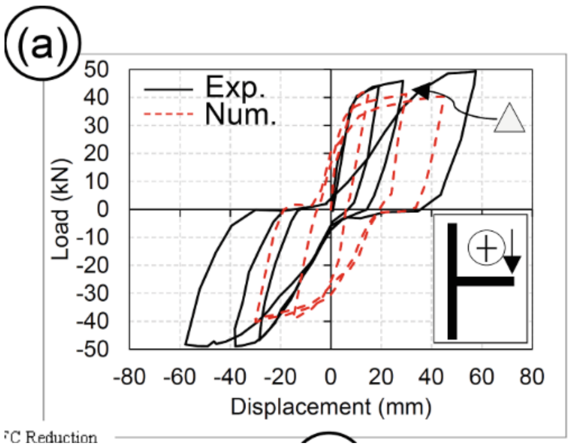
2DP	KAKU's SPECIMEN

Source	Marchisella A, Muciaccia G. RC Beam-Column Joints as Membrane Elements: An Application of MCFT. In: Fib SYMPOSIUM: International Symposium of the International Federation for Structural Concrete. Springer Nature Switzerland; 2023:509--519. doi:10.1007/978-3-031-32511-3_54
Elements	2D plane stress
Software	ATENA / MEMBRANE 2000
Material	Non-linear concrete (smeared crack) / Non-Linear steel reinforcement (Bond-Slip with memory)
Analysis	Non-linear Quasi-Static
Reference Model [Experimental]	Kaku T, Asakusa H. Bond and anchorage of bars in reinforced concrete beam-column joints. ACI Spec Publ. 1991;123:401-424.
Reference Model [Numerical]	NA

Model



Results



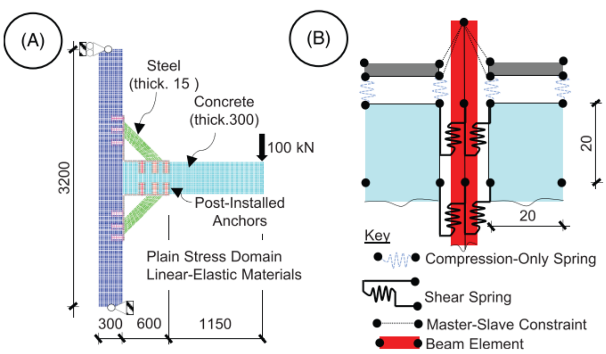
Comments

See Marchisella A, Muciaccia G. RC Beam-Column Joints as Membrane Elements: An Application of MCFT. In: Fib SYMPOSIUM: International Symposium of the International Federation for Structural Concrete. Springer Nature Switzerland; 2023:509--519. doi:10.1007/978-3-031-32511-3_54.

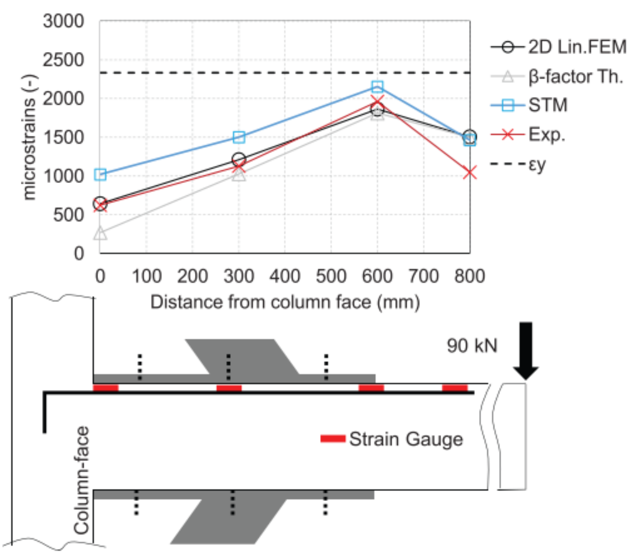
2DP	GENESIO's RC BEAM-COLUMN JOINT

Source	Marchisella A, Muciaccia G. Haunch retrofit of RC beam – column joints : Linear stress field analysis and Strut-and-Tie method application. 2023;(May):1-25. doi:10.1002/eqe.3921
Elements	2D Plane stress
Software	SAP2000
Material	Linear-Elastic Concrete / Compression-only grout / Linear-Elastic Steel plates / Linear-Elastic steel rod (bond-slip law)
Analysis	Linear Static
Reference Model [Experimental]	Genesio G. Seismic Assessment of RC Exterior Beam- Column Joints and Retrofit with Haunches Using Post-Installed Anchors. 2012.
Reference Model [Numerical]	NA

Model



Results



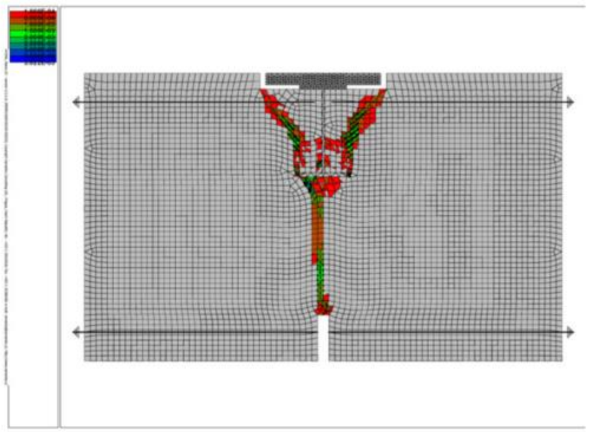
Comments

See Marchisella A, Muciaccia G. Haunch retrofit of RC beam – column joints : Linear stress field analysis and Strut-and-Tie method application. 2023;(May):1-25. doi:10.1002/eqe.3921.

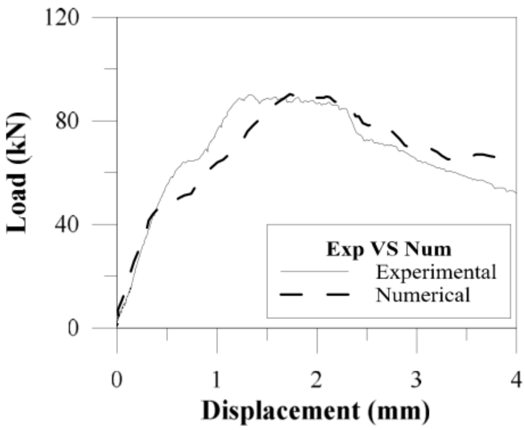
2DP	LARGE HEAD ANCHOR IN CRACKED CONCRETE

Source	Di Nunzio G, Marchisella A, Muciaccia G. Influence of head-size on concrete cone capacity: a comparison for two cast-in solutions. In: 12th Fib International PhD Symposium in Civil Engineering. Prague; 2018:187-194.
Elements	2D Plane stress
Software	ATENA
Material	Non-Linear concrete (MCFT) / Linear-Elastic steel reinforcement (perfect bond)
Analysis	Non-Linear Static
Reference Model [Experimental]	Di Nunzio G, Marchisella A, Muciaccia G. Influence of head-size on concrete cone capacity: a comparison for two cast-in solutions. In: 12th Fib International PhD Symposium in Civil Engineering. Prague; 2018:187-194
Reference Model [Numerical]	NA

Model



Results



Comments

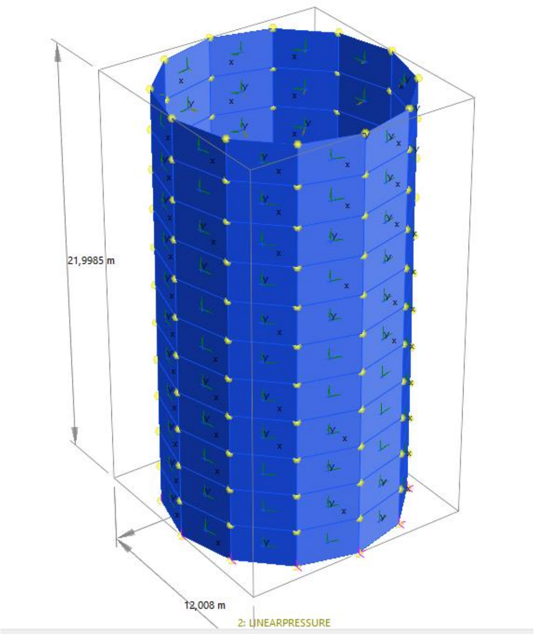
See Di Nunzio G, Marchisella A, Muciaccia G. Influence of head-size on concrete cone capacity: a comparison for two cast-in solutions. In: 12th Fib International PhD Symposium in Civil Engineering. Prague; 2018:187-194.

PLATES and SHELLS

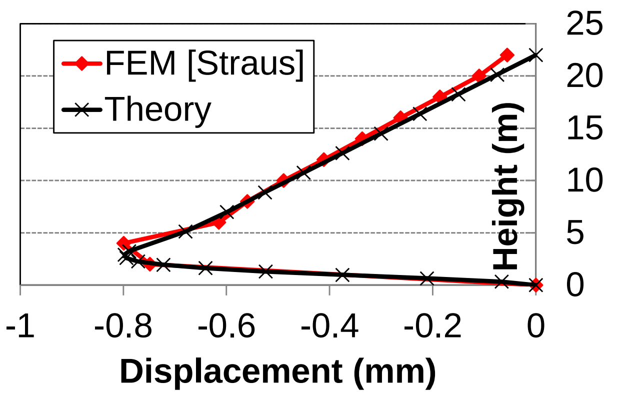
SHE	CYLINDRICAL TANK

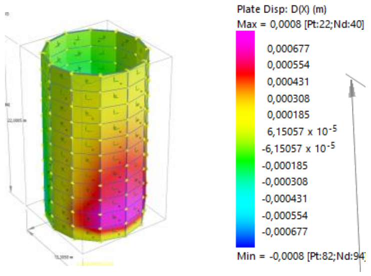
Source	Personal Archive
Elements	SHELL
Software	STRAUS-7
Material	Linear-Elastic
Analysis	Linear-Static
Reference Model [Experimental]	NA
Reference Model [Numerical]	Timoshenko S. *Plate and Shells*. McGraw-Hill; 1959.

Model



Results





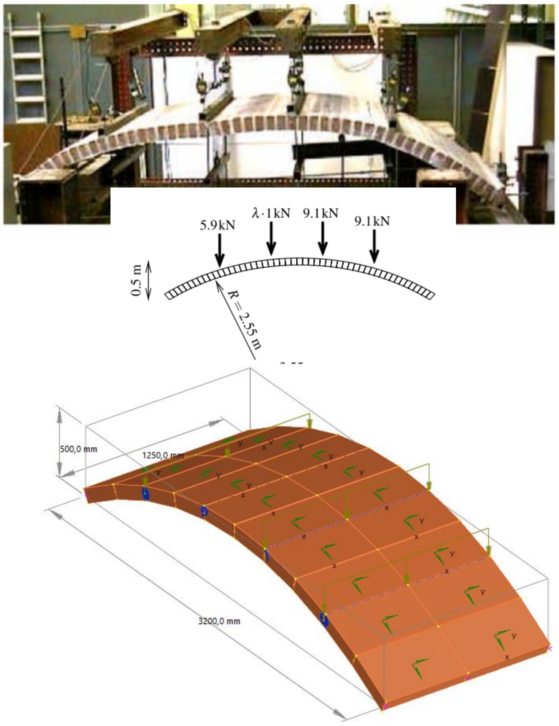
Comments

The scope of the numerical investigation was to verify the ability of shell elements, implemented in STRAUS-7, in reproducing the displacement field of the cylindrical shell under water-type pressure distribution (internal). Agreement with respect to analytically-derived results was found.

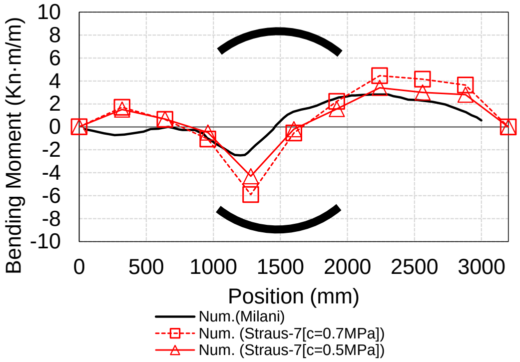
SHE	VERMELTFOORT’s ARCH

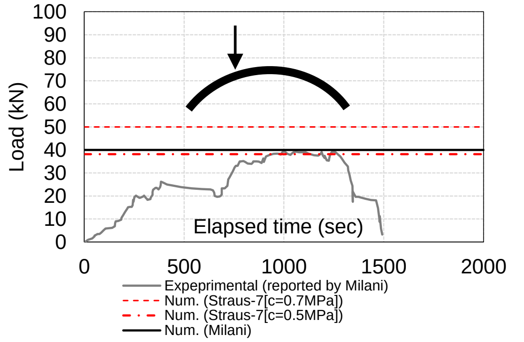
Source	Personal Archive
Elements	SHELL
Software	Straus-7
Material	Non-Linear Brick (Mohr-Coulomb)
Analysis	Non-Linear Static
Reference Model [Experimental]	NA (Reported by Milani, 2008)
Reference Model [Numerical]	Milani E, Milani G, Tralli A. Limit analysis of masonry vaults by means of curved shell finite elements and homogenization. Int J Solids Struct. 2008;45(20):5258-5288. doi:10.1016/j.ijsolstr.2008.05.019

Model



Results





Comments

The numerical investigation addressed masonry arch tested up to collapse. Scope of the investigation was to show how simple Mohr-Coulomb (MC) criterion combined with rectangular finite elements (arch was discretized by 10 segments) can be useful tool in predicting the load-carrying capacity. Joints were not modeled. Calibration of the MC’s cohesion parameter was needed whereas friction angle was kept equal to 45°. Agreement with respect to both experimental and independent numerical (Milani,2008 using curved shell element) results was found.

SHE	**THOMSEN's SHEAR WALL**

Source	Personal Archive
Elements	SHELL (MultiLayer)
Software	OPEN SEES
Material	Non-Linear Concrete
Analysis	Non-Linear Quasi-Static
Reference Model [Experimental]	Thomsen J, Wallace JW. Displacement-Based Design of Slender Reinforced Concrete Structural Walls - Experimental Verificatio. J Struct Eng (United States). 2015;9445(April 2004):1562-1569. doi:10.1061/(ASCE)0733-9445(2004)130
Reference Model [Numerical]	NA

Model

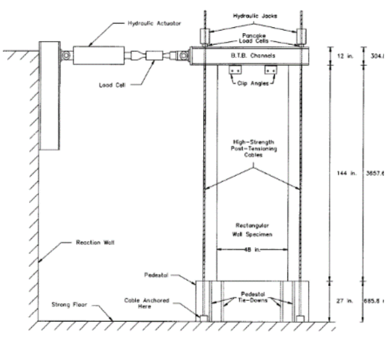
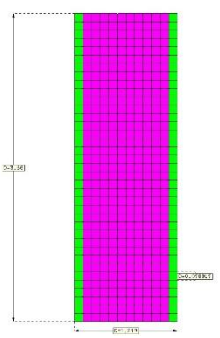
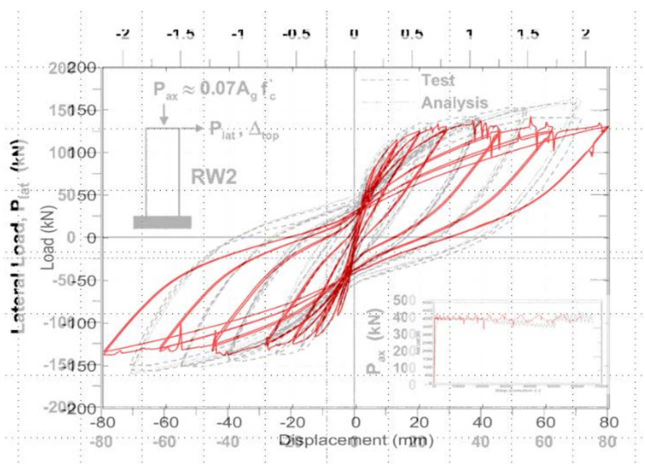


Fig. 11. Specimen test setup—RW1 and RW2



Results



Numerical

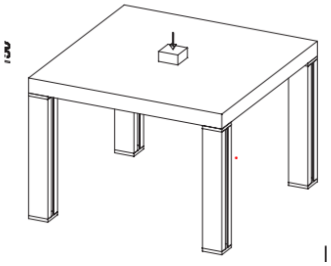
Comments

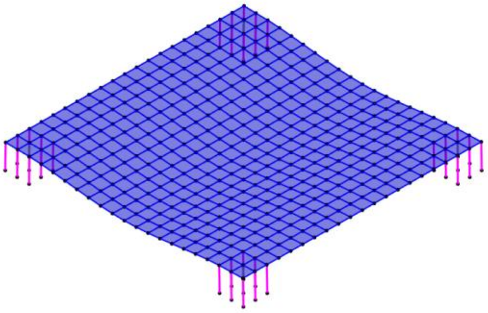
The numerical investigation addressed an RC shear wall (flexural critical) tested cyclically. The wall was modeled using multi-layer shell element, viz. concrete layer coupled with reinforcement layers. Agreement with respect to experimental result was found both for backbone and hysteresis characteristic of the load-to-displacement curve.

SHE	POURZARABI's RC PLATE

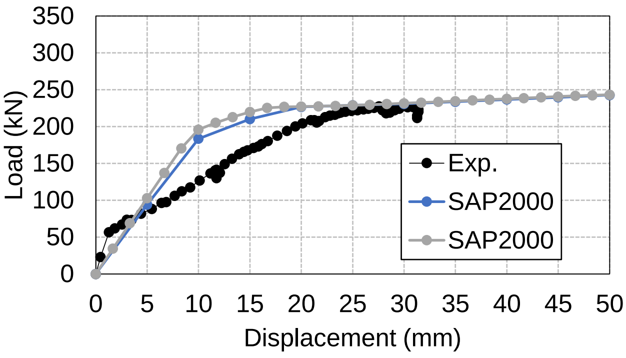
Source	Personal Archive
Elements	SHELL(Multi-Layer)
Software	SAP2000
Material	Non-Linear Concrete / Non-Linear Steel
Analysis	Non-Linear Static
Reference Model [Experimental]	di Prisco M, Colombo M, Pourzarabi A. Biaxial bending of SFRC slabs: Is conventional reinforcement necessary? Mater Struct Constr. 2019;52(1):1-15. doi:10.1617/s11527-018-1302-0
Reference Model [Numerical]	NA

Model





Results



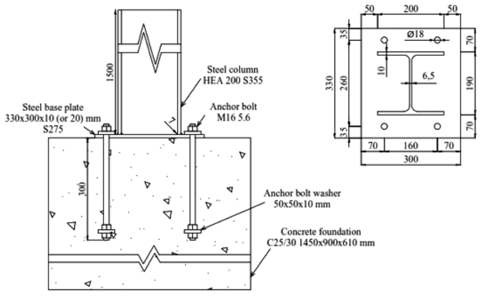
Comments

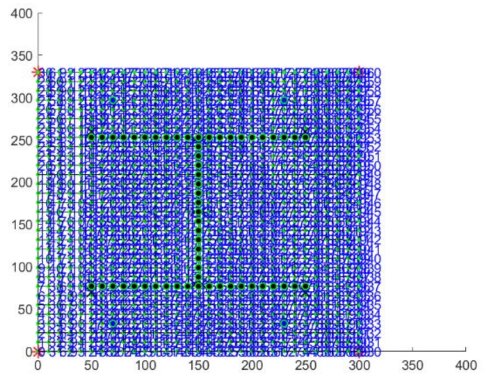
The numerical investigation addressed an RC slab (flexural critical). The slab was modeled using multi-layer shell element, viz. concrete layer coupled with reinforcement layers. Agreement was found with respect to the predicted load-carrying capacity. Difference in stiffness are recognizable, most probably due to lack of modeling correspondence of restraints conditions.

SHE	SILVA DA SECO’s BASE PLATE

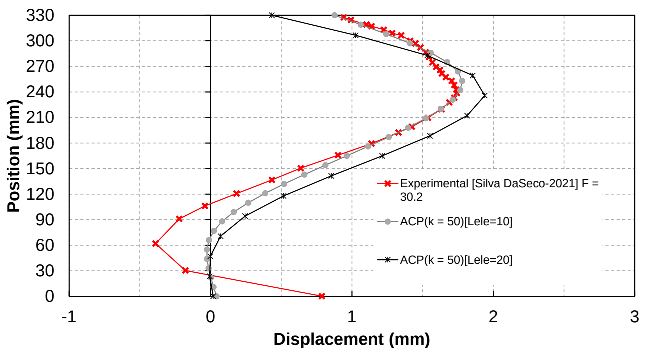
Source	Personal Archive
Elements	PLATE
Software	Flexible Base Plate (Developed by A. Marchisella)
Material	Linear Elastic steel / Compression-only concrete
Analysis	Non-Linear Static
Reference Model [Experimental]	Da Silva Seco L, Couchaux M, Hjiaj M, Neves LC. Column base-plates under biaxial bending moment. Eng Struct. 2021;231(January). doi:10.1016/j.engstruct.2020.111386
Reference Model [Numerical]	NA

Model





Results



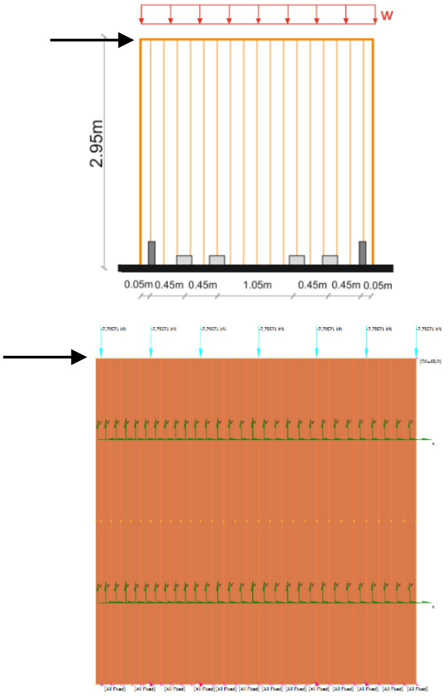
Comments

The numerical investigation addressed column base-plate tested under uni-axial bending. Steel plate was modeled using shell elements. Anchors were modeled using springs. Concrete pad was modeled using compression-springs. Attached element was not explicitly modeled but a kinematic constraint was give to ll the nodes belonging to the profile’s footprint. Agreement was found with respect to experimental displacements (measured via digital-image-correlation). Results slightly depended on the adopted mesh size.

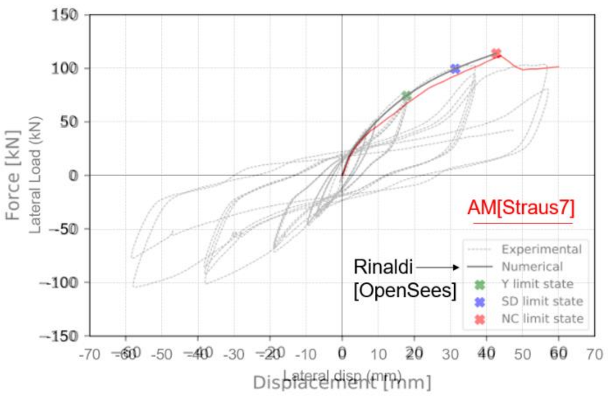
SHE	**GAVRIC's TIMBER PANEL**

Source	Personal Archive
Elements	SHELL / SPRINGS
Software	STRAUS 7
Material	Linear Elastic (Ortho) / Non-Linear Spring
Analysis	Non-Linear Static
Reference Model [Experimental]	Gavric I. Seismic Behavior of Cross-Laminated Timber Buildings. 2011.
Reference Model [Numerical]	Rinaldi V. The Seismic Behavior of CLT Timber Buildings: Evaluation of the Behavior Factor for the Revision of Eurocode 8. 2021.

Model



Results

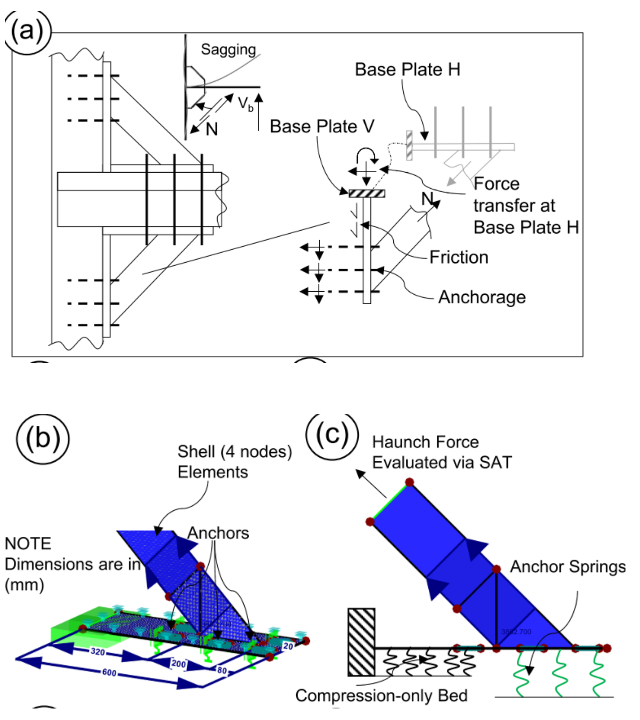


Comments

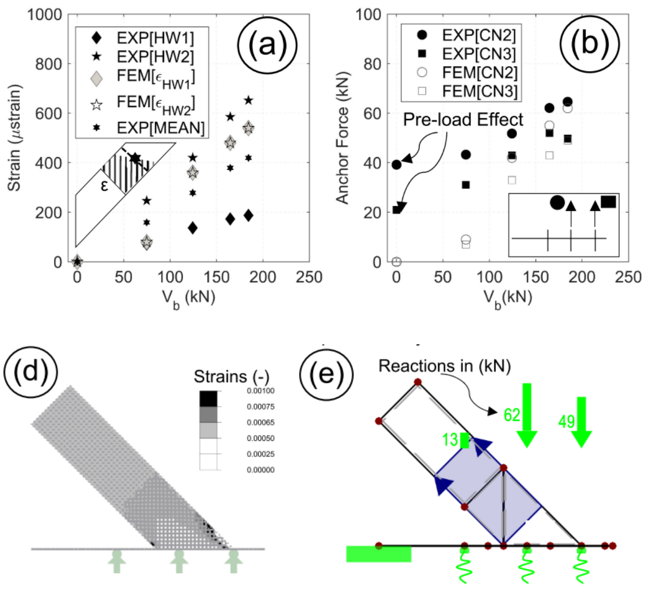
The scope of the numerical investigation was to verify the reliability of modeling metal devices (hold-down and angle brackets) used to connect the timber panel to concrete foundation as uni-axial springs. Constitutive laws, given to the springs, were non-linear. Agreement with respect to both experimental and independent numerical results was found.

Source	Marchisella A. Seismic Assessment of Existing 3D RC Beam-Column Joints and Retrofit with Fully Fastened Haunch. 2022. http://hdl.handle.net/10589/187062.
Elements	SHELL / SPRINGS
Software	RFEM
Material	Linear-Elastic steel / Non-Linear Spring
Analysis	Linear-Static
Reference Model [Experimental]	Marchisella A. Seismic Assessment of Existing 3D RC Beam-Column Joints and Retrofit with Fully Fastened Haunch. 2022. http://hdl.handle.net/10589/187062.
Reference Model [Numerical]	NA

Model



Results



Comments

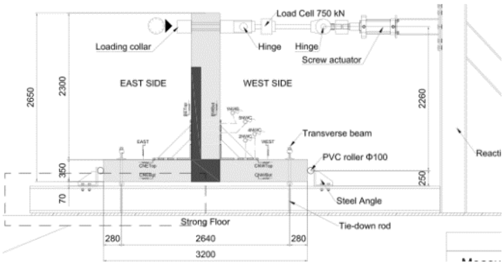
The numerical investigation addressed haunch element used to retrofit RC beam-column joint. Sub-modeling technique was employed, in only the a convenient static equivalent portion of the sub-assemblage was analyzed. Comparison of both strains and anchors' forces was possible showing a good agreement only for the latter.

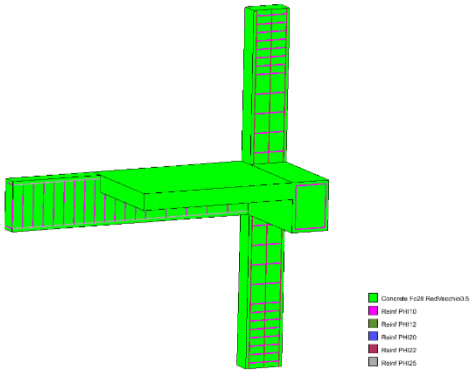
3D – BRICK / AXISYMMETRIC

3DB	RC BEAM-COLUMN JOINT with SLAB

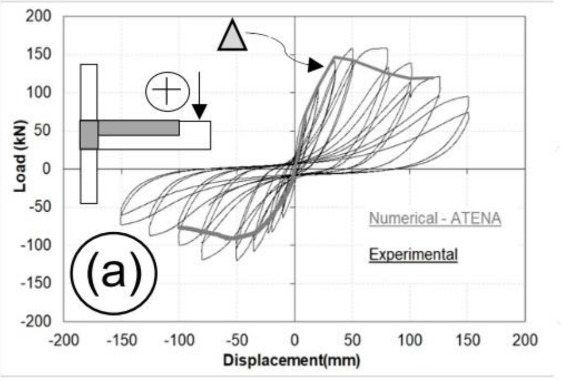
Source	Marchisella A. Seismic Assessment of Existing 3D RC Beam-Column Joints and Retrofit with Fully Fastened Haunch. 2022. http://hdl.handle.net/10589/187062.
Elements	3D brick
Software	ATENA
Material	Non-linear concrete (smeared crack) / Non-Linear steel reinforcement (perfect bond)
Analysis	Non-linear
Reference Model [Experimental]	Marchisella A, Muciaccia G, Sharma A, Eligehausen R. Experimental investigation of 3d RC exterior joint retrofitted with FFHR. Eng Struct. 2021;239(July):112206. doi:10.1016/j.engstruct.2021.112206
Reference Model [Numerical]	NA

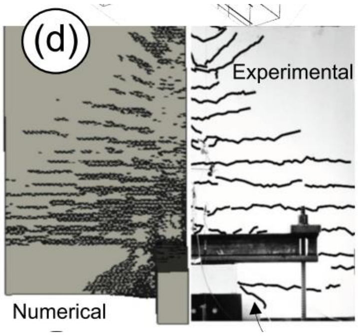
Model





Results





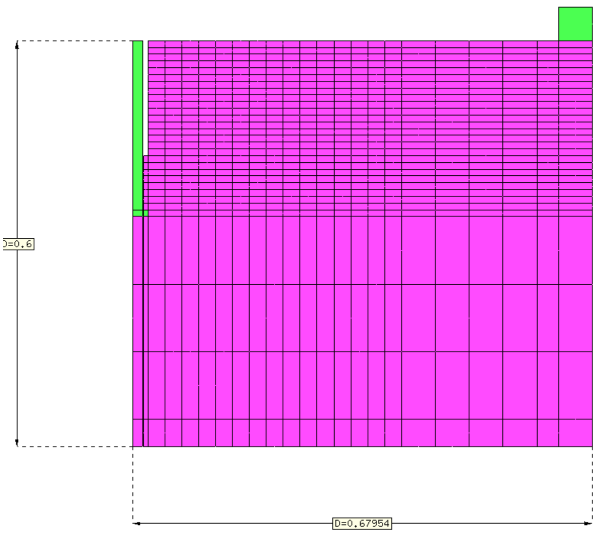
Comments

The numerical investigation addressed an exterior RC beam-column joint with slab of transverse beam. Three-dimensional model was employed to investigate the torsional behavior of the transverse beam. Agreement with respect to experimental result was found both for load-carrying capacity and non-symmetric load-to-displacement response.

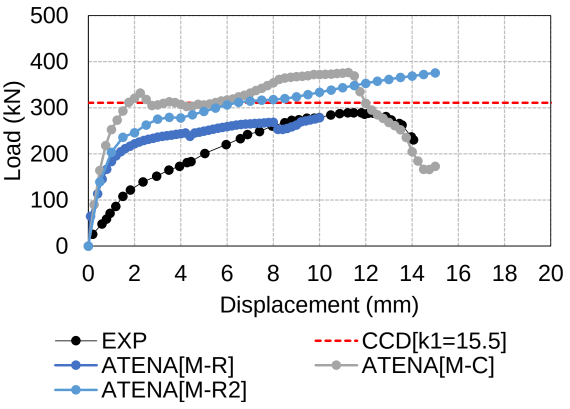
ELIGEHAUSEN 's HEADED ANCHOR

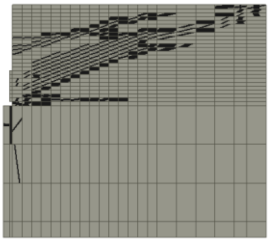
Source	Personal Archive
Elements	Axisymmetric
Software	ATENA
Material	Non-Linear concrete
Analysis	Non-Linear
Reference Model [Experimental]	Eligehausen R, Sawade G. A fracture mechanics based description of the pull-out behavior of headed studs embedded in concrete. Fract Mech Concr Struct. 1989:281-299. doi:10.18419/opus-7930
Reference Model [Numerical]	

Model



Results





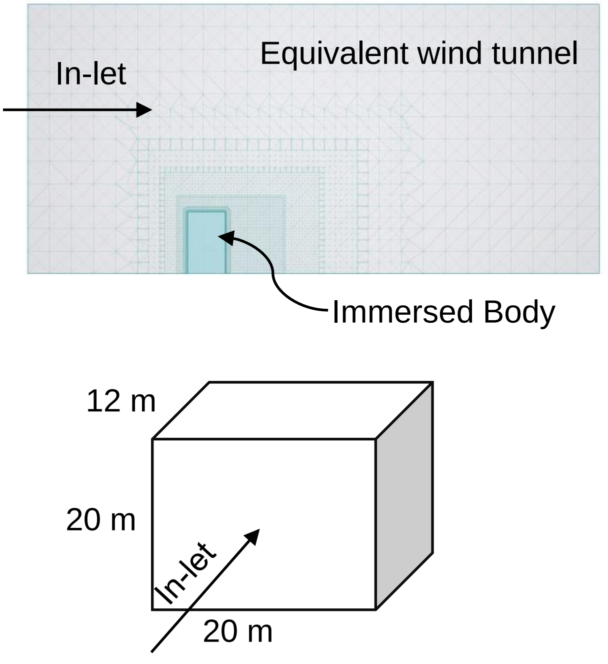
Comments

The numerical investigation addressed a single anchor (headed stud) tested under tensile load. Axisymmetric model was employed. Agreement with respect to experimental result was found for load-carrying capacity. Lack of accuracy in stiffness prediction was most probably due to inability of reproducing large compressive strain at the head zone. Differences associated to meshes were recognized.

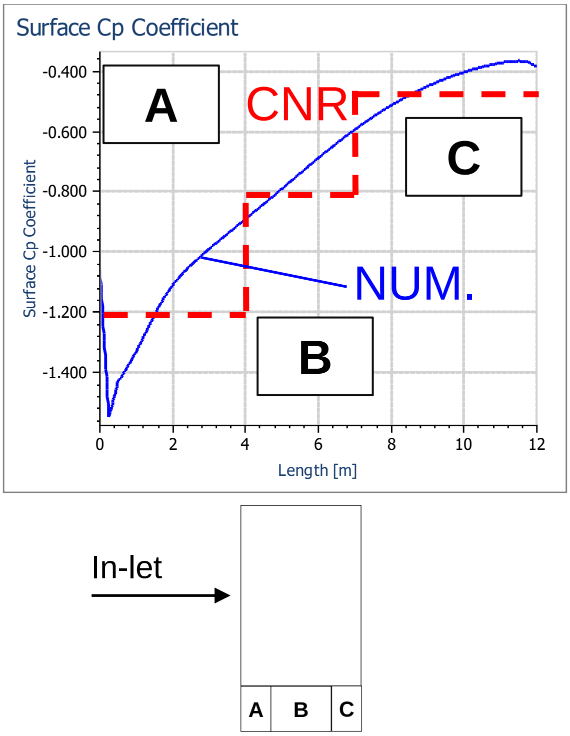
3DB	CFD on SIMPLE BUILDING

Source	Personal Archive
Elements	3D Brick
Software	RRWIND (see Dlubal. RWIND Generation of Wind-Induced Loads on General Models. 2012)
Material	Incompressible turbolent flow – Static Body (without aeroelastic effect)
Analysis	Computational Fluid Dynamics (CFD)
Reference Model [Experimental]	NA
Reference Model [Numerical]	CNR. CNR-DT 207/2008 Istruzioni per la valutazione delle azioni e degli effetti del vento sulle costruzioni. 2008.

Model



Results



Comments

The numerical investigation addressed the problem of a building under wind load condition. A fluid-mechanics simulation of the flow around objects in an equivalent wind tunnel was applied. Comparison of pressure coefficients was made with respect to provisions provided by an Italian technical document addressing wind effect on structures.