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EXCHAIN – Collaborative Platform and Database to share experimental data, results and acquired knowledge

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Abstract

The design of engineering structures like it is done today and in the past is based on static calculations. The consideration of uncertainties in the model quality becomes more and more important with the development of new construction methods and design requirements. In addition to the traditional forced-based approaches, experiences and observations about the deformation of components and the overall structure under different exposures, lead to novel detection and evaluation criteria.

This continuous process can be observed and followed by code development, respectively. Accessible knowledge collected and provided on database will indeed play an essential role for future decisions. Additionally, the use of machine learning methods which require training data is becoming more and more common. Therefore, the establishment of a database, in which experimental results, information and acquired knowledge are collected and provided for future common activities in research and education, becomes more and more important.

The network of the EU funded Erasmus+ strategic partnership between Universidade de Aveiro, Budapest University of Technology and Economics, University of Ljubljana, Josip Juraj Strossmayer University of Osijek, and Bauhaus-Universität Weimar created such a collaborative platform to share existing and future experimental data, results, and acquired knowledge with researchers all around the world. The different expertise, research work, and facilities from the partners are brought together for easier common use and application. Quite often data from experiments conducted in the past cannot be easily accessed for many reasons (e.g. compatibility, change of responsibilities, etc.).

This paper addresses the database created in the project and the currently available datasets. At the same time, those interested are encouraged to use the database for their purpose and to provide additional data sets for wider use and usability for others. Based on the synopsis of the available data sets, information on the scope, completeness, and examined parameters is presented. In accordance with the objective of providing not only data but also information, results of analytical investigations are assigned to the experiments, too. The aim is to provide the users with access to the available results and models.

Keywords: database; experiments; laboratory tests; pushover analysis

1. Introduction

The seismic analysis and design of complicated structures, such as tall buildings, long-span bridges, etc. cannot rely on assuming static forces and elastic structural response only. On the other hand, by considering the dynamic nature of seismic action and inelastic response of the structure in the analysis, new uncertainties will challenge the design engineer; such as uncertainty about structural response, deformations, etc. One common approach to overcome the uncertainties is to conduct experiments on equivalent models of the structure or structural elements and record the results and observations which can then be used to make an estimate of the variable under investigation.

In this regard, the researchers may also refer to the experimental results of the others for further evaluation. Therefore, it is crucially beneficial and informative to create platforms on which the experimental results are stored and accessed. A database is a common form of such platforms which has become more common by the rapid growth of the internet and communication. The database EXHCAIN has been created to store and share variety of experimental data for this purpose.

The network of the EU funded Erasmus+ Strategic Partnership between Universidade de Aveiro, Budapest University of Technology and Economics, University of Ljubljana, Josip Juraj Strossmayer University of Osijek, and Bauhaus-Universität Weimar created such a collaborative platform to share experimental data, results and acquired knowledge (into a common accessible database). The different expertise, research work, and facilities from the partners are brought together for easier common use and application.

This article introduces the database EXCHAIN (Fig. 1), created as described in the above project, and describes the currently available datasets. Firstly, the research works, the papers and the articles are classified into three groups; this is necessary since the experimental data and results on the database were taken from them. Secondly, the definition of “test setup” and “experiment” together with some other terms used on the database are presented. Finally, a brief overview of the available experiments and results is provided.

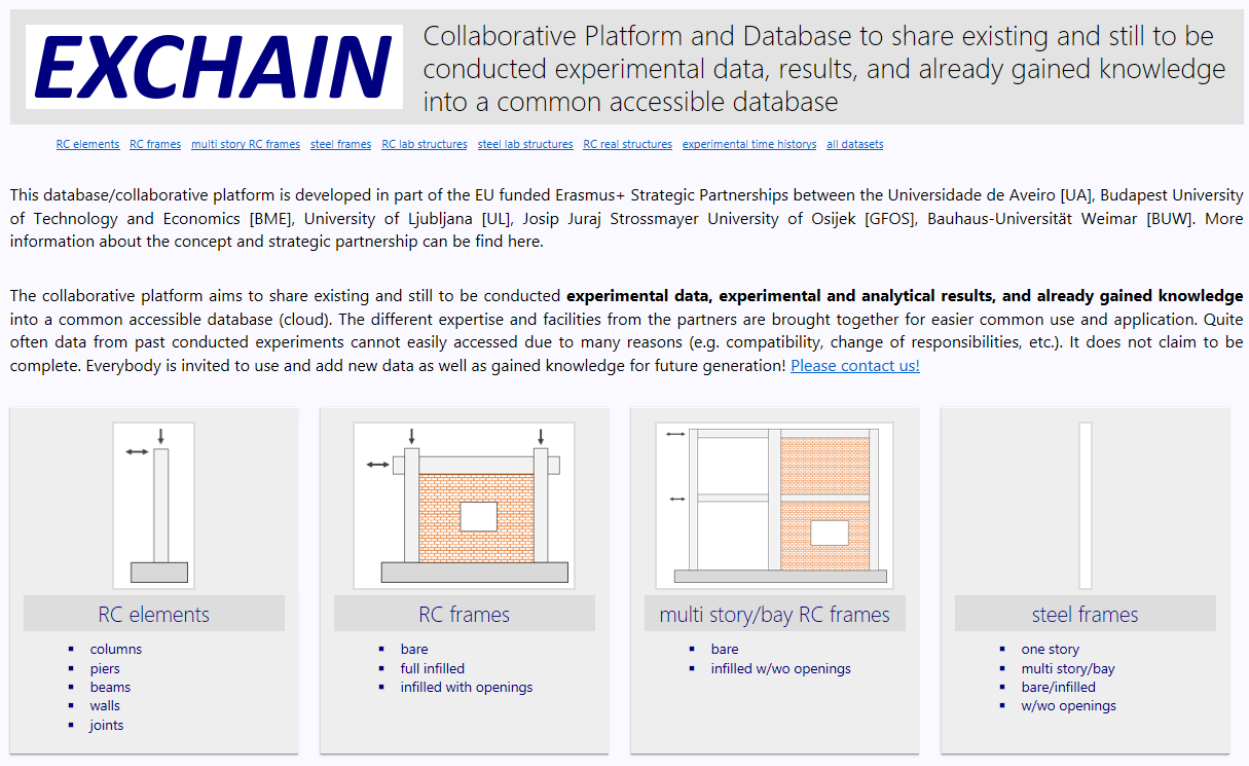


Fig. 1 – The homepage of database EXCHAIN at https://exchain.edac.biz.

2. The Database EXCHAIN

The Erasmus+ SP project focused on support to shape innovative developments in civil engineering, intercultural exchange, and to improve professional, social, and language skills of excellent junior staff. At the center of the partnership was the exchange of knowhow in the fields of earthquake engineering, steel and bridge construction, mathematical models and structural analysis.

In part of the strategic partnership, additionally a collaborative platform was established to share existing and future experimental data, results, and already gained knowledge into a common accessible database. The different expertise, research work, and facilities from the partners were brought together for easier common use and application. Quite often data from experiments conducted in the past cannot be easily accessed due to many reasons (e.g. compatibility, change of responsibilities, etc.). The elaborated collaborative platform and database is available at: http://exchain.edac.biz .

2.1 Structure of the Database

The data sets of the EXCHAIN database are hierarchically structured and are based on corresponding publications. That means all data are linked to the original author and publication. All relevant information from a publication must be manually transferred to the specified file structure. The EXCHAIN application can then import this file structure automatically and import it into a database. This database is then the source for a web front-end that makes the test results available on the website (Fig. 1).

The file and folder structure is divided into 3 levels: "Publication", "Test Setup" and "Experiment". The level "Publication" stands for the entire document (e.g. article, conference contribution, etc.), the level "Testsetup" stands for a relevant diagram in this document (e.g. diagram with pushover curves) and the level "Experiment" stands for a curve in this diagram. Thus, a publication can contain several "test setups" (diagrams) and a "test setup" can contain several "experiments" (test curves).

The whole database design is arranged in a way that new structural types can be easily added, whereas the sub-structure has to be typically followed. It will allow an easy access to the data via scripts (Fig 2). [Note. The necessary front-end is currently under development!]

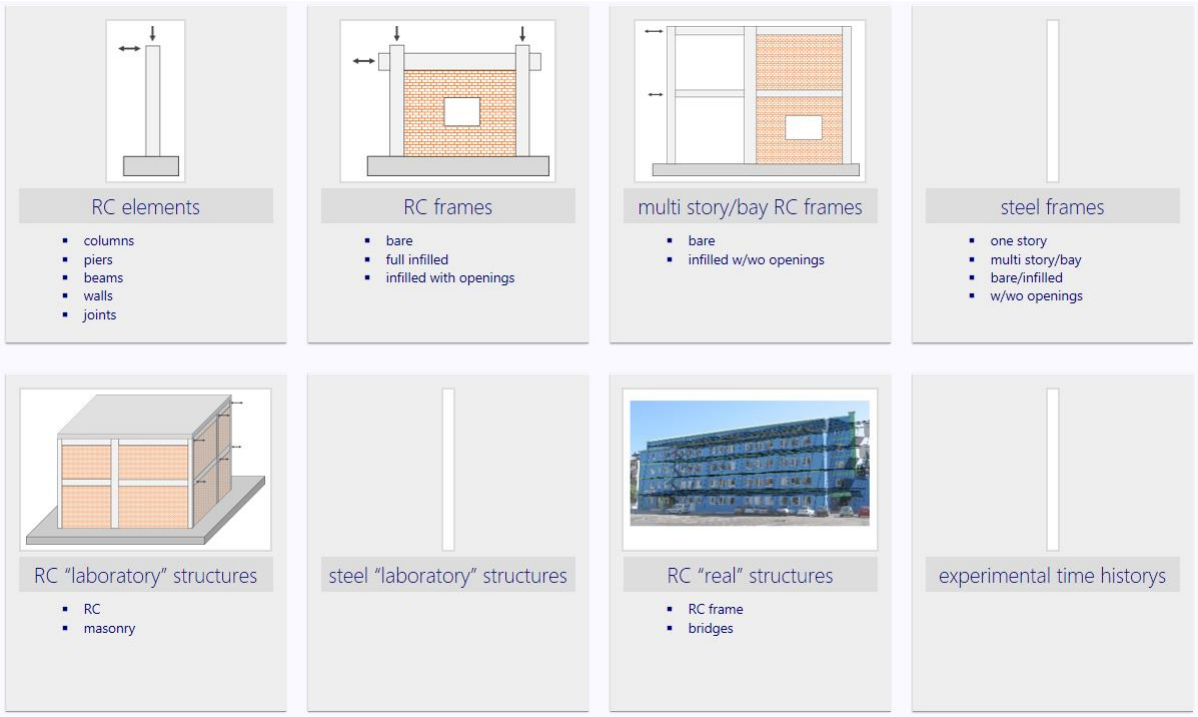


Fig. 2 – First order categories – structural types – of the EXCHAIN database.

2.2 Publication

For each publication, a publication folder and a file "pub_data.txt" must be created. The information in the file is stored in key-value pairs. The following information have to be provided and are used: Title of the publication; Reference for publication; Year of publication; Publication type (The following publication types are currently available in the database: Proceedings, Article, Book, Unpublished, WebPage, Master Thesis, PhD Thesis); Authors of the publication; General description of the publication. Furthermore, it is possible to insert images in the description text.

The publication folder must also contain a subfolder "pics" and a subfolder "downloads". In the folder "pics" the pictures have to be saved, which should appear in the description text of the publication. In the folder "downloads" files can be stored which are to be made available for download via the web frontend (for example PDF file of the publication).

2.3 Test Setup

For each diagram with relevant information in the publication, a test setup folder and a file "tsp_data.txt" has to be created in the publication folder. The information in the file is stored in key-value pairs just as in "pub_data.txt". The following information have to be provided and are used:

- Name of the "test setup";
- Test setup type, this type is not arbitrary. The following options are possible so far: "RC element", "RC frame", "multi story RC frame", "RC lab structure", "RC real structure", and "Steel lab structure";
- Name of the X- and Y-axis of the diagram (for example "Displacement");
- Unit of the X- and Y-axis of the diagram (for example "mm");
- Number of floors, if determinable for the selected test setup type, otherwise blank line;
- General description of the test setup, analogous to the publication description the insertion of images is possible. The image file must be saved in the subfolder "pics" of the test setup folder.

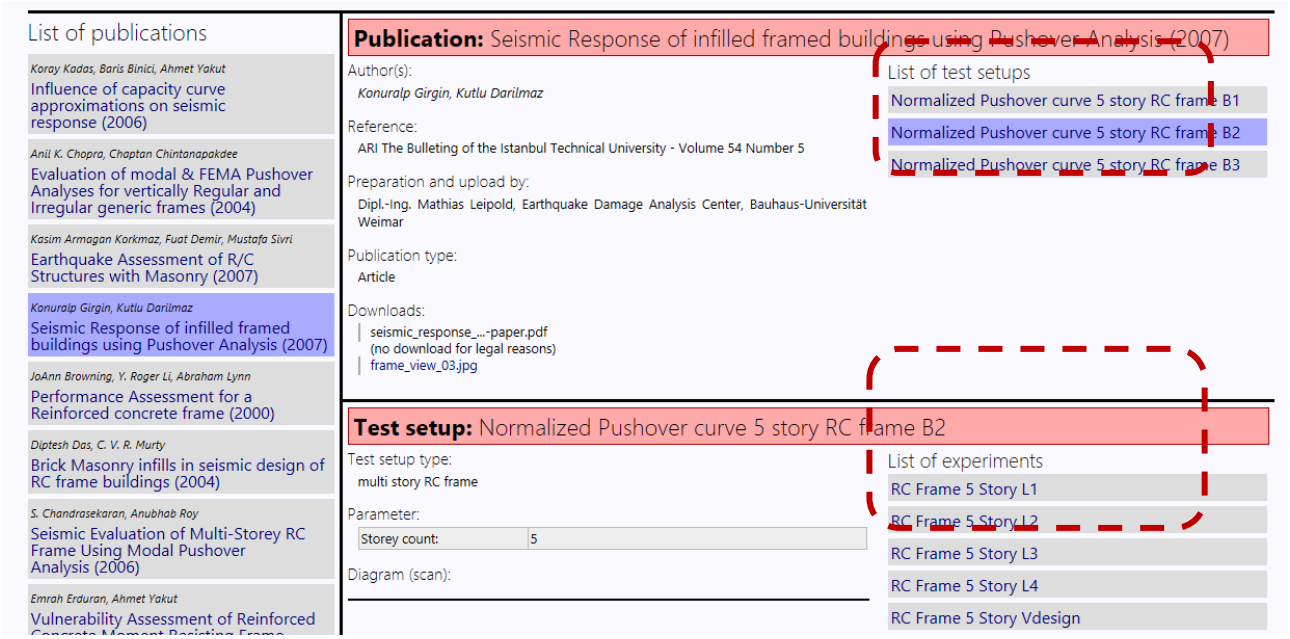


Fig. 3 – List of test setups and experiments (*website snapshot*).

The test setup folder must also contain a subfolder "pics" (see above), a subfolder "downloads" and a subfolder named "diagram". In the folder "pics" the pictures have to be saved, which should appear in the description text of the test setup. In the folder "downloads" files can be stored which are to be made available for downloading via the web front-end (for example files from calculation programs). The folder "diagram" must contain exactly one image file that shows the diagram underlying the test setup.

2.4 Experiment

For each relevant curve in the current diagram, an experiment folder and a file "exp_data.txt" has to be created in the test setup folder. The information in the file is stored in key-value pairs just as in pub_data.txt. Table 1 summarize the information to be provided and are used:

Table 1 – Input/Parameter of the level 3 “experiment (state Feb. 2020).

Input/Parameter	**Options & Units** *[currently in the database]*	**Explanation**
Name of the "experiment"		
Experiment type	- Analytical pushover - experimental pushover - experimental time-history	This type is arbitrary.
Source of the curve	- this publication - recalculation by [author], [reference]	Typically, the curve is taken from the publication. However, it is also possible to insert curves derived from a separate (re)calculation of the published results.
Filename (*original/digitized curve*)		Name of the file with the values of the original/digitized curve.
Filename (*linearized curve*)		Name of the file with the values of the linearized curve.
Line type - original/digitized curve - linearized curve	- continuous - dash - dot	As to be shown in the web front-end diagram. This type is not freely selectable.
Line color - original/digitized curve - linearized curve	- black, red, green, blue - yellow, cyan, magenta - gray, light-red, light-green - light-blue and light gray	As to be shown in the web front-end diagram. This color is not freely selectable.
Concrete and/or steel and/or masonry strength	- as value (e.g. 28) - as value range (e.g. 28 to 32) - blank line if not available	The units are predefined and values have to be added/given in MPa. [*internal transformation is not foreseen*]
Modulus of elasticity of concrete and/or steel and/or masonry	- as value (e.g. 25000) - as value range (e.g. 23000 to 25000) - blank line if not available	The units are predefined and values have to be added/given in MPa. [*internal transformation is not foreseen*]
Moment of inertia	- as value (e.g. 370000) - as value range (e.g. 370000 to 390000) - blank line if not available	The units are predefined and values have to be added/given in cm^4. [*internal transformation is not foreseen*] Provide this value for Test setup type "RC element".
General description	*Analogous to the publication description.*	The image file must be saved in the subfolder "pics" of the experiment folder.

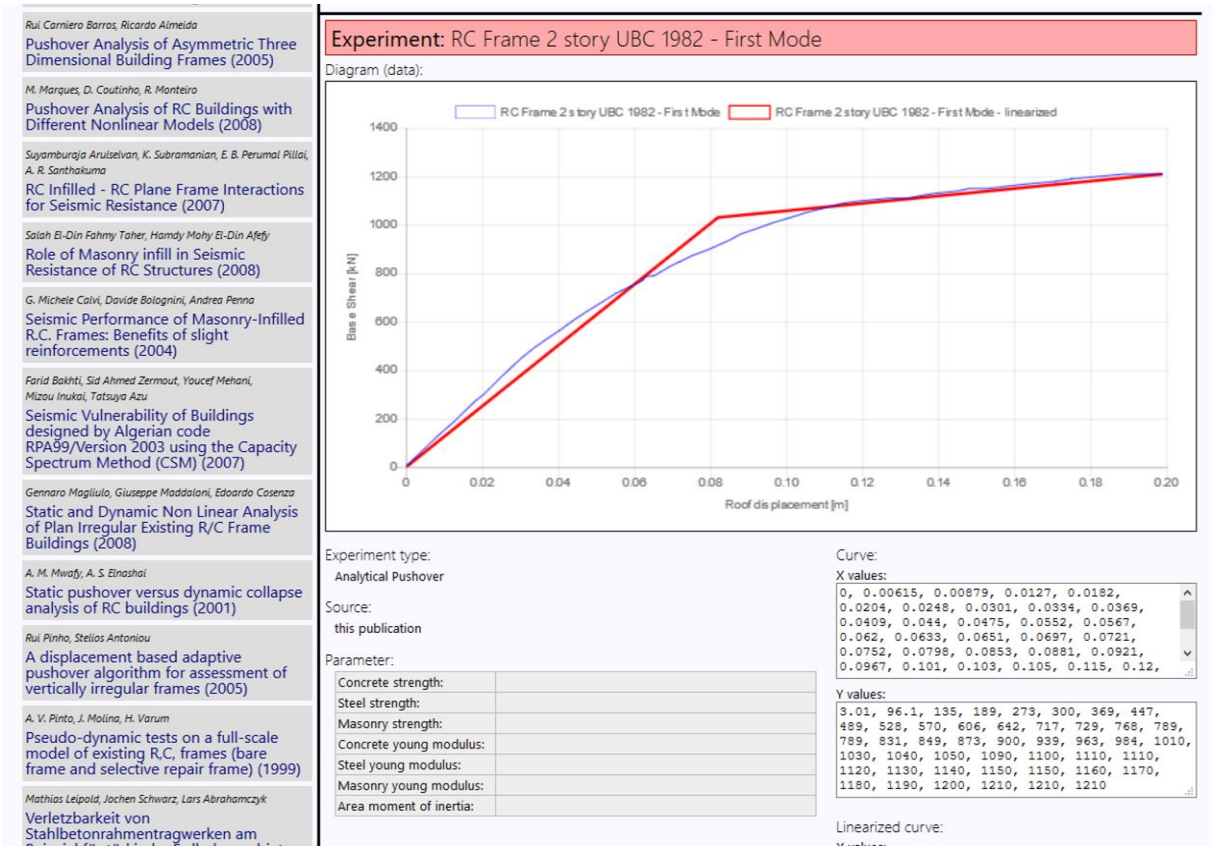


Fig. 4 – Example view of level 3 “experiment” (*website snapshot*).

The experiment folder must also contain a subfolder "pics" (see above) and a subfolder "downloads". In the folder "pics" the pictures have to be saved, which should appear in the description text of the experiment. In the folder "downloads" files can be stored which are to be made available for downloading via the Web frontend (for example files from calculation programs). The experiment folder must also provide the data files of the curve (and if available, the linearized curve).

3. Data Assessment

3.1 Classification of Studies/Publication

Researchers pursue particular objectives in their studies. An overall overview of all the papers submitted and uploaded so far to the database could divide them into three groups as following:

Group 1: Evaluation of current or classical methods, approaches or assumptions with focus on pushover analysis.

The goal or objective is to find out which of the current methods leads to the most accurate force-displacement curve. This is usually done thorough a comparative study. For example, different patterns of incremental lateral load are assumed and the pushover curve is then compared with the result of time history dynamic analysis. In this case, it is common to assume an incremental PGA of the ground motion to develop a force-displacement curve for time history dynamic analysis as well. The pushover curve is then compared with the dynamic analysis curve; smaller deviation from the dynamic analysis curve shows a higher accuracy of the pushover analysis which has resulted by the initial assumptions. (sample article [1, 2])

Group 2: Assessment of behavior or response of structures under horizontal (e.g. seismic) loads

The goal or objective of the study is to understand the performance (mostly inelastic response) of the structural system under seismic load thorough pushover analysis. For instance, to investigate whether or not the code criteria can assure the expected inelastic behavior of the frame, designed to the code, the ultimate capacity of the frame, known as complete collapse point, can be estimated by pushover analysis.

Assessment of the behavior of an existing building which has experienced an earthquake can also fall in this group. In such a case, the goal is to evaluate, for example to what extent the building can resist future earthquakes. This is usually done by modeling the damaged building and running pushover analysis for it. (sample article [3]).

The other case of study in this group is to examine different assumptions in modeling structures; for example, assumptions in modeling shear walls, infill masonry walls, etc. The pushover curve obtained through different assumptions are then compared with the dynamic analysis curve of the model and smaller difference between two curves shows more accurate assumption in modeling. (sample article [4])

Group 3: Developing new methods or improving the current methods of seismic analysis

The goal of the study is to understand inefficiency or inaccuracy of the current methods or assumptions in "seismic analysis" and to propose a solution for it. "Seismic analysis" here refers to the methods used for assessment of structural response or performance under seismic load. This could be the classical pushover analysis itself. For example, how to implement higher modes of vibration in pushover analysis; or how to consider change in natural period of structure (caused by formation of plastic hinges) in the analysis. (sample article [5, 6])

The difference between the study in this group and the first group is the distance which the researcher usually takes from the classical or current method. Here, the researchers open up a problem statement and they tend to put forward a solution which is usually based on changing the principle assumptions in the analysis. They may re-structure the procedure in order to eliminate the error. For example, assumption of adaptive stiffness matrix or adaptive load vector in pushover analysis of irregular frames.

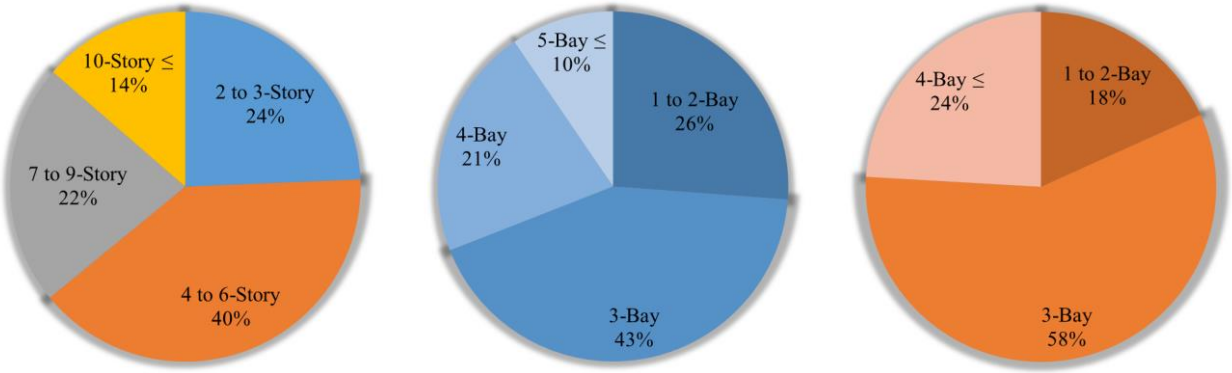
It is noteworthy to highlight that the point of the above classification is to show the application of pushover analysis. The goal of the database is not to classify the submitted papers or studies, rather to bring together the experimental data and results and make a library of them for the researchers. For this purpose, the properties of the structural frames and the basic assumptions made in the experiment are also provided on the website.

Group 2 is the largest class (with 47%) so far followed by group 3 (29%) and group 1 (24%) which may show the most common application of pushover analysis in earthquake engineering.

Table 2 – Categorize of experiments on the website (state Feb. 2020)

No.	Category	Share to database [%]
1	RC elements	7
2	RC frame	31
3	Bay RC frame	49
4	Steel frame	5
5	RC "laboratory" structure	4
6	Steel "laboratory" structure	< 1
7	RC "real" structure	3
8	Experimental time history[*1]	< 1

[*1] … so far not further classified, but indicating the type of data.



a) Frames, grouped by story count

b) 2 to 3-story frames, grouped by bay count

c) 4 to 6-story frames, grouped by bay count

Fig. 5 – Available configuration for "Multi story/bay RC frames".

3.2 Categorization of Data Sets/Experiments

Over decades of study and research in the field of earthquake engineering, simplified approaches like the classical pushover analysis has been improved and corrected constantly; consideration of modal lateral load, reduction in stiffness of the structure due to formation of plastic hinges, etc. are some examples for the improved pushover analysis, which is used today. This continuous process can be observed and followed by code development, as well.

Pushover analysis results of variety of structures, collected and held on a database which is accessible to the researchers, could indeed play an essential role for future improvements. Therefore, pushover analysis is the largest group of experiment, which is currently available on EXCHAIN database.

The researchers in the field of earthquake engineering at the universities all around the world publish numerous papers and articles every year. Pushover analysis has been at the center of their study for the past few decades. Either they choose pushover analysis as the subject of their study and try to improve it; or they use pushover analysis in their study as a tool to measure or evaluate structural performance.

Every paper submitted to the database is carefully read and reviewed; through which the structures or buildings used in Pushover analysis, the parameters and assumptions in the analysis and the force-displacement curve obtained by Pushover analysis, are extracted and represented on the website.

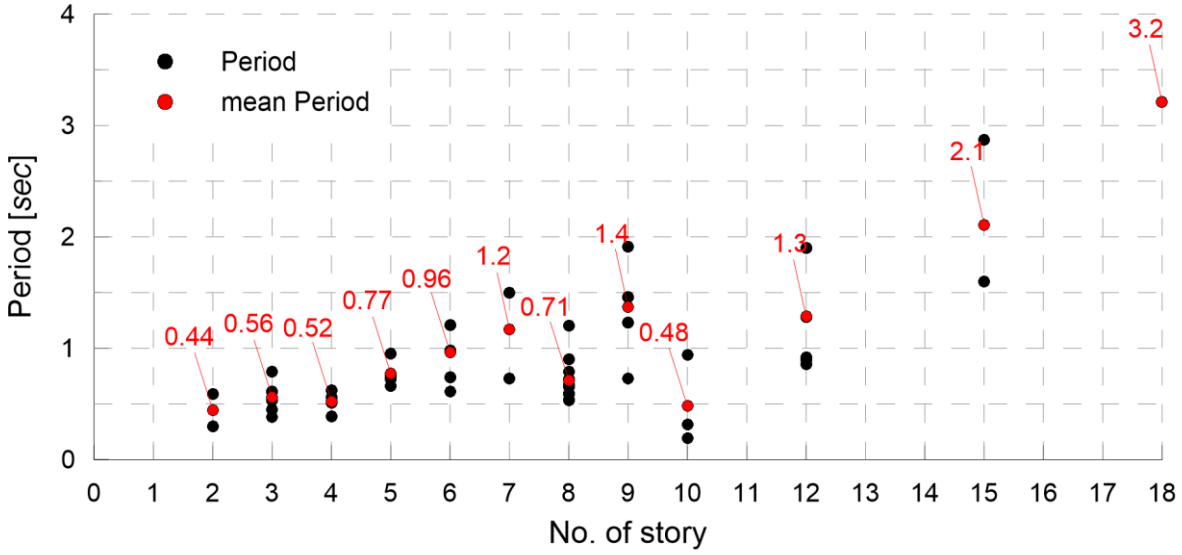
In the following section, the papers submitted to the database are classified into three groups and the application of Pushover analysis in them will be described.

The test setup configuration together with the assumptions and parameters used in the experiment are extracted from the article and they are stored in text files. This means each article has several tags in "txt" format. A code has been written in MATLAB to read the "txt" files and to tabulate them. This could make it possible to compare the experimental data of all articles on the database together. The code will be further developed to be implemented or published on the website that researchers can approach the datasets easier.

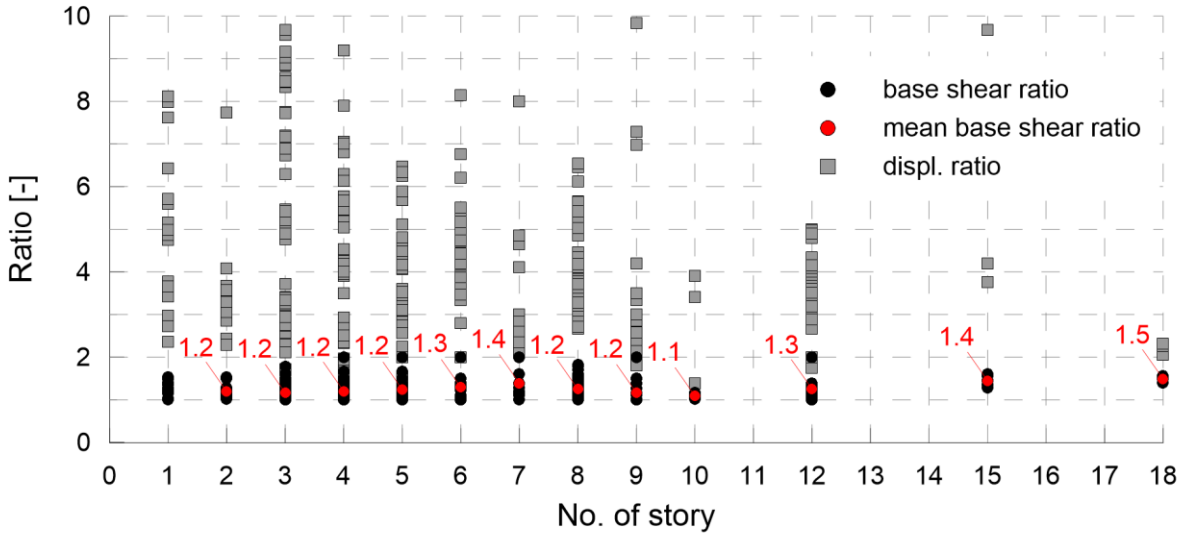
There are 8 categories of experiments available on the website (Table 2 and Fig. 2). Categorization is based on the type of "test setup" used in the experiment. "Multi story/bay RC frames" is currently the largest category and "RC elements" comes after that.

The largest category, "Multi story/bay RC frames", contains RC-frames with variety of configurations. 40% of the total frames in this category, have 4 to 6 stories; among them 58% are 3-Bay frames. This means "4-story/3-bay" to "6-story/3-bay" frames are the most common test setups on the database. The available configurations have been illustrated in Fig. 5.

Story-height of the frame ranges between 2.4 to 4.2 m and bays vary in span from 2.0 to 9.1 m. The periods of vibration of the frames in the first mode are between 0.2 s to 3.5 s.



a)



b)

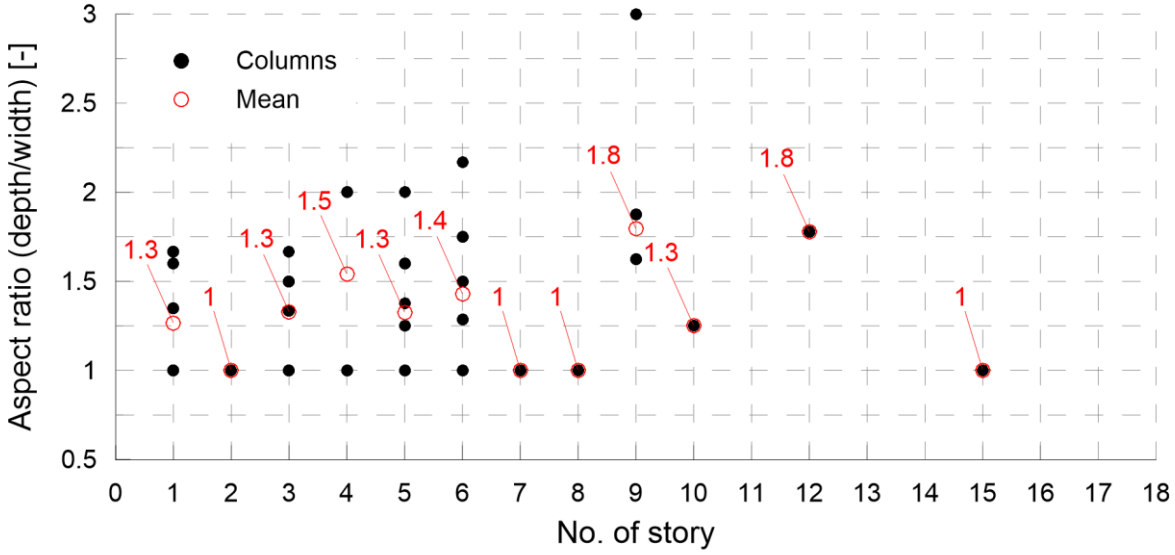
Fig. 6 – Range and mean value of: a) periods b) ductility and strength ratio.

One of the important outcomes of the Pushover analysis among researchers is the ratio of base shears at yield and collapse, Eq. (1) as well as the ratio of ultimate and yield displacement [8].

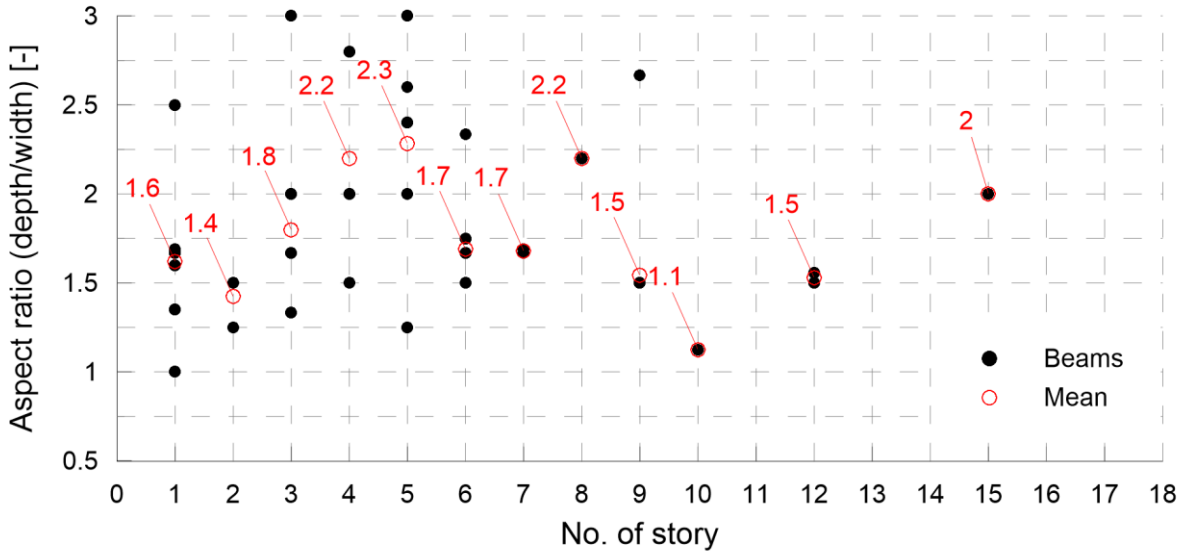
$$q_{BS} = \frac{collapse\ base\ shear}{yield\ base\ shear} \tag{1}$$

$$q_{Displ.} = \frac{ultimate\ \text{displacement}}{yield\ \text{diesplacement}} \tag{2}$$

Mean value of q_{BS} for a frame with particular number of stories (a test setup) is estimated by calculating q for all experiments on the frame and taking the average of them. Mean values of the period of the first mode, column and beam sections aspect ratio are estimated in the same manner. Fig. 6 and 7 show the range and mean value of these parameters respectively.



a)



b)

Fig. 7 – Range and mean value of: a) columns; b) beams aspect ratio.

RC-frames with 4, 6, 9 and 12 stories were selected and their pushover curves plotted together in Fig. 8. The vertical axis of the graphs shows the base shear coefficient of the frame, which is calculated with Eq. (3). The horizontal axis shows the roof displacement divided by the total height of the frame.

$$base\ shear\ coefficient = \frac{base\ shear}{total\ weight} \tag{3}$$

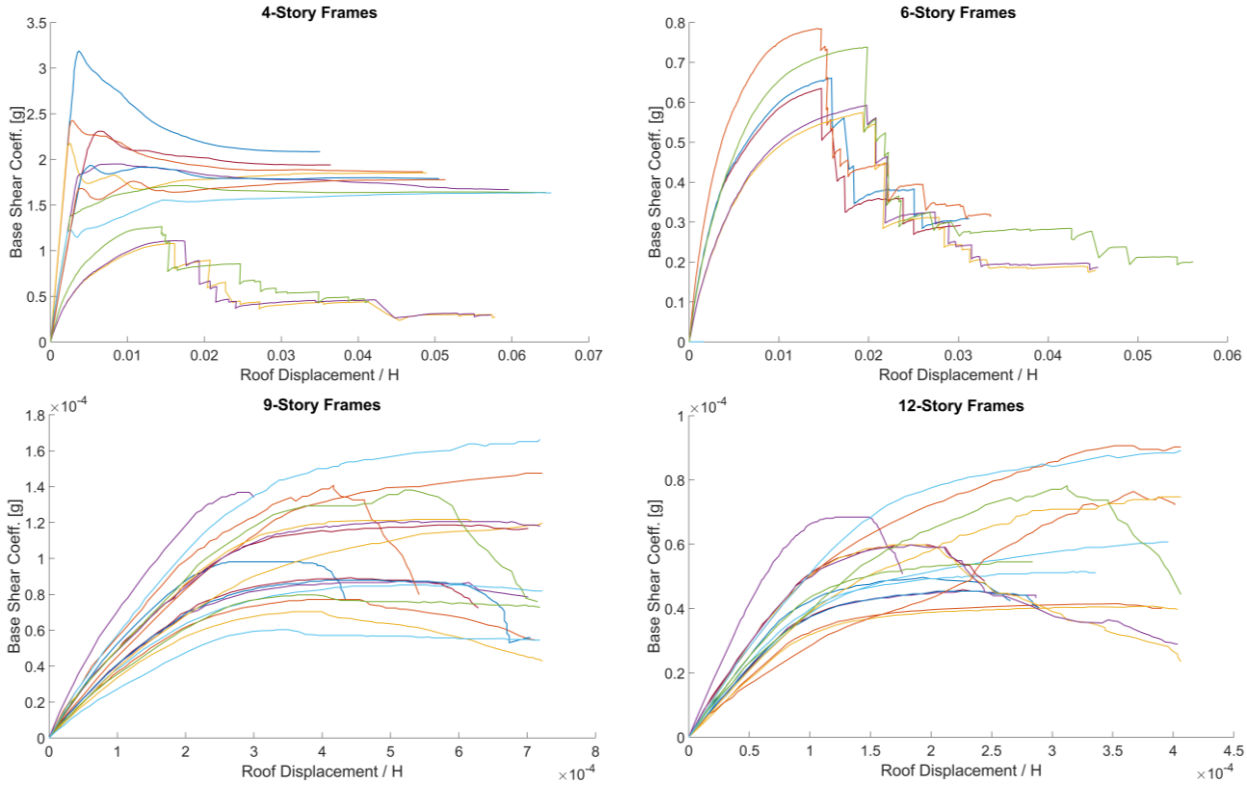


Fig. 8 – Pushover curves of selected groups of frames.

In calculation of the base shear coefficient, only experiments have been used which had all the required information such as the frame configuration, total weight, etc.

Plotting pushover curves of a number of frames together has been previously done by researchers as an attempt to develop simplified functions which are able to describe the behavior and expected damage for a certain group of buildings [7]. The procedure to determine bilinear curve of the pushover curves is in accordance with [7]. The readers are invited to refer to the article for further detail.

4. Conclusion

The database EXCHAIN as a platform for sharing knowledge obtained through experiment, was introduced. Three groups of studies and researches (where the available experiments on the website come from) were discussed to show the wide application of pushover analysis. The configuration of test setups on the database were presented by some statistics and the mean value of period, q factor, beam and column sections were discussed.

In the end, the authors would like to open an invitation to all researchers to share their experiments and results with EXCHAIN to help the platform to grow up further.

5. Acknowledgements

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