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Assessment of the ACI-DAfStb Database of Shear Tests on Slender Reinforced Concrete Beams without Stirrups for Investigations on the Shear Capacity Scatter

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Assessment of the ACI-DAfStb Database of Shear Tests on Slender Reinforced Concrete Beams without Stirrups for Investigations on the Shear Capacity Scatter

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Abstract

The shear transfer mechanism of RC slender members without stirrups still presents very high uncertainties and the question has generated many controversies and debates since the beginning of the last century. Regrettably, until now the real causes of this problem are not yet clear to the scientific community and the issue is still important to investigate, especially nowadays that the minimizing of natural resources is of uppermost global interest.

Due to the increased laboratory costs, actual studies are more and more often devoted to numerical simulations based on previous experiments. Unfortunately, it is difficult to find test results suitable for investigations on the shear capacity scatter in the available specialized literature.

Therefore, the objective of this paper is to provide different adequate sets of reported test results containing tests performed on almost identical beams. The ACI-DAfStb database of shear tests on slender reinforced concrete beams without stirrups is considered and analyzed through the use of both multivariate statistical methods and clustering data mining techniques. The database was firstly visually explored by scatterplots and investigated through both univariate and correlation statistical procedures, and then processed by clustering using the k-means algorithm. Similar sets of data were collected in groups of comparable experiments. Clusters containing less than six data sets were removed. The criteria to establish the rate of similarity between each set of data were chosen according to the JCSS Probabilistic Model Code.

The study has led to the formation of 13 groups of comparable experiments each group containing a number of tests between 6 and 43, performed generally by different field workers. These groups of reported test results will be of great importance both for the continuation of the authors' research and for other researchers who investigate the causes of the shear failure scatter or develop improved shear design methods.

Keywords: Shear strength • Reinforced concrete members • Multivariate statistical methods • Data clustering • Probabilistic Model Code

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Introduction

Shear failures are sudden and catastrophic in nature and should be avoided in the design process.

The shear strength of RC members without web reinforcement is a subject that has generated many controversies and debates since the beginning of the last century; a brief and pedagogical historical presentation was presented by Rebeiz (1999). All the researchers that have tested the shear capacity of reinforced concrete members without web reinforcement have observed a large scatter in the results. Even simple members cast simultaneously of the same concrete batch may show significant differences in the shear capacity. Silfwerbrand (1984) measured, e.g., 15 percent in tests on overlaid concrete beams. As far as the topic is concerned, an interesting compilation was made by ACI and ASCE (1962). In the cited reference, it was shown that the shear failure load can differ with 100 percent for RC beams with identical or almost identical geometry and material data. A later review of research data performed by Rahal (2000) from 161 beams shows that the scatter can be even 120 percent.

Shear failure is a diagonal tension phenomenon and occurs when the principal tensile stresses exceed the diagonal tensile strength of the member. However, as frontiersmen of the subject have stated (Kreffeld and Thurston 1966), it is difficult to determine the strength of cracked RC members because their internal force system is not known with certainty (reinforced concrete is a composite, nonhomogeneous, and nonisotropic material that cracks significantly under relatively low loads). Moreover, as reported by Park and Paulay (1975) and later confirmed by the joint ASCE-ACI Committee 445 (1998), the diagonal cracking load originating from flexure and shear is usually much smaller than would be expected from both a principal stress analysis and the tensile strength of concrete; this condition is largely due to the presence of shrinkage stresses. Therefore, the shear capacity of RC members without web reinforcements, well represented by the diagonal cracking shear strength (Mphonde and Frantz 1984), is sensitive to both the observer’s judgment and the location of the initial flexural cracks, and this may increase the scatter of the values experimentally determined (Bazant and Kazemi 1991).

Unfortunately, until now the real causes of the considerable variability of the shear capacity of reinforced concrete members without web reinforcement are not yet clear to the scientific community and it is still important to investigate this issue; especially nowadays that the minimizing of natural resources is of uppermost global interest.

Since the laboratory costs have increased rapidly during recent years, actual studies are more and more often devoted to numerical simulations based on experiments realized several decades ago.

Researchers who deal with this topic need reported test results containing tests on almost identical beams. Regrettably, it is difficult and time-consuming to find suitable test cases in the comprehensive literature on shear and shear strength capacity.

The objective of this paper is to provide different adequate sets of reported test results containing tests performed on almost identical beams to researchers interested in the shear mechanism of reinforced concrete members without stirrups.

The Methodology

The ACI-DAfStb Database

The ACI-DAfStb evaluation database of shear tests on RC members without shear reinforcement subjected to point loads and uniformly distributed loads was considered and analysed. The "evaluation-level" database contains 784 tests on slender beams, including 40 tests on beams with uniformly distributed loads. For each experiment, the informations provided by the shear database are summarized in the following main categories: (1) the mechanical properties of concrete, (2) the reinforcement area and strength, (3) the geometrical properties of the cross-section, (4) the load, and (5) the measured ultimate shear capacity. Each category contains different recorded variables. For more details on the shear database, the reader is referred to Reinek et al. (2013).

Data Analysis

Multivariate data are data with many variables; such data generally include control variables (*factors*) and characteristics (*responses*). Multivariate data analysis consists of a search for systematic covariance between all factors and responses through methods that look at all the sample properties simultaneously.

Referring to the shear database, the sets of variables including between the mentioned categories 1 and 4 belong to factors, the remaining set of variables comprehended in category 5 belongs to responses. For each test, the collection of all the different variable values is visualized as a point in a multidimensional space.

The raw database was firstly visually explored by scatterplots and analyzed through both univariate and correlation statistics methods. Because of both the heterogeneity of the database and its highly nonlinear structure, more advanced linear statistical investigations were not considered at this stage.

The shear database was then processed by clustering using the k-means algorithm (MacQueen 1967; Anderberg 1973; Jain and Dubes 1988; Kaufman and Rousseeuw 1990). Cluster analysis divides data objects into groups (*clusters*) basing only on information found in the data that describes the objects and their relationship. The goal of this kind of analysis is that the objects within a group be similar (or related) to one another and different from (or unrelated to) the objects in other groups. The greater is the similarity (or homogeneity) within a group and the greater is the difference between groups, the better or more distinct is the clustering. K-means is a prototype-based (a cluster is defined as a set of objects in which each object is closer to the prototype that defines the cluster than to the prototype of any other cluster; the prototype of a cluster is often the centroid, i.e., the mean value of all the points in the cluster), partitional (simply division of the set of data objects into non-overlapping clusters) clustering technique that attempts to find a user-specified number of clusters k (Tan, Steinbach and Kumar 2006).

Cluster analysis was performed assuming just five variables (the geometrical parameters) be representative of the similarity between the different experimental tests; these variables are characterized by: (i) the width of web b_w, (ii) the height of beam h, (iii) the effective depth d_s, (iv) the shear-to-span ratio a/d, and (v) the area of reinforcing steel A_s. This quite restrictive (but satisfactory for the aim of the study) assumption was defined basing on the idea that researchers who deal with the shear failure scatter are interested in tests performed on almost identical beams where the likeness mainly refers to a visual point of view; that means that, considering constant the load configuration, the similarity between cases can be related just to the similarity between the geometrical parameters. Because of its simplicity, in the k-means algorithm, the use of Euclidian distance metric was preferred.

The number of clusters k was chosen iteratively and heuristically. The final number of clusters k was set at 89 and determined by examining and selecting a solution that resulted in the fewest number of clusters that maintained the standard deviation on each of the cross-section geometrical parameters (b_w, h, d_s, and A_s) within a cluster consistent with the value given by the JCSS Probabilistic Model Code (i.e., high internal homogeneity). The shear-to-span ratio a/d was no taken into consideration in this case.

According to the JCSS Probabilistic Model Code, if no further information is available, the statistical characteristics of the mentioned cross-section geometrical parameters may be assessed by:

$$\sigma(b_w, h) = 4 + \mu(b_w, h) \cdot 0.006 \leq 10 \text{ mm} \quad (1)$$

$$\sigma(d_s) \cong 10 \text{ mm} \quad (2)$$

$$\sigma(A_s) = \mu(A_s) \cdot 0.02 \quad (3)$$

The choice of the JCSS Probabilistic Model Code as an external measure for assessing the clusters quality, as reported in Vrouwenvelder (2002), is due to the fact that it gives guidance on the modelling of the random variables in structural engineering. The number of repetitions of the clustering process, each with a new set of initial cluster centroid positions, was set at 250; just the solution with the lowest value for the within-cluster sums of point-to-centroid distances was considered. In order to assess the quality of the individuated clusters, the within-cluster similarities and the cluster silhouettes (Rousseeuw, 1987) were calculated and plotted.

The samples reliability first was grossly examined: only clusters containing more or equal to six data sets were considered as “Possibly Reliable

Sample" while the others were counted as "Uninteresting Background" (were not taken into consideration for the aim of the study). Each of the *n* individuated possibly reliable samples was then visually explored by scatterplots and analyzed through both univariate and correlation statistics methods. As previously mentioned, the main assessment procedure consisted in comparing the standard deviation of each of the cross-section geometrical parameters (b_w, h, d_s, and A_s) within a cluster to the value given by the JCSS Probabilistic Model Code as follows:

$$\sigma(b_w, h, d_s, A_s)_{Group} / \sigma(b_w, h, d_s, A_s)_{JCSS} \leq 1 \quad (4)$$

If Eq. (4) was not satisfied, the search restarted from the cluster analysis modifying the number of the k-means partitions. All possible noise was carefully controlled and removed. Conclusively, the treatment of each group of comparable experiments was left to the final judgment of the authors. The method flowchart is shown in Fig. 1. All the calculations were performed using the MATLAB Statistics Toolbox.

Computational Results

The scatter plots with marginal histograms of the shear capacity V_u of the reinforced concrete beams without stirrups reported in the ACI-DAfStb evaluation database with respect to their main geometrical parameters are represented in Fig. 2. The main geometrical parameters are here summarized in: (a) the width of web b_w, (b) the height of beam h, (c) the shear-to-span ratio a/d, and (d) the area of reinforcing steel A_s.

The same diagrams are again shown in Fig. 3, this time with respect to both the main mechanical and concrete composition parameters: (a) the geometric percentage of longitudinal reinforcement ρ_{sw}, (b) the max diameter of aggregates Φ_a, (c) the uniaxial compressive strength of concrete f_{lc}, and (d) the test value for axial tensile strength of concrete $f_{lct,test}$.

The number of bins *m* in the histograms is taken according to the following empirical relationship (Haldar and Sankaran 2000):

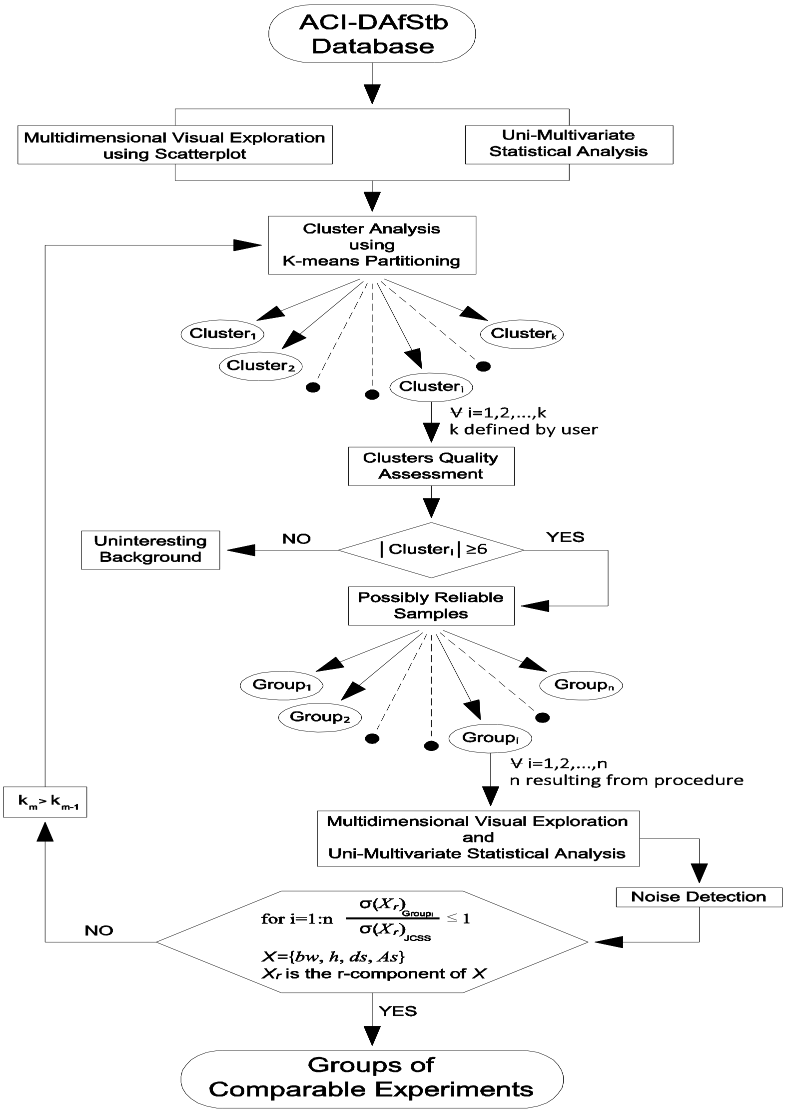
$$m = 1 + 3.3 \lg n \quad (5)$$

where *n* is the number of samples. Because of its strict correlation with the height of beam *h*, the effective depth d_s is not shown in the mentioned scatter plot; it was, however, considered important in the cluster analysis.

In order to visually display the clustering results, the cluster silhouettes for the final number of 89 clusters are plotted in Fig. 4.

The groups' descriptions, their statistical characteristics, and the quality assessment criteria can be found in the Appendix. The Appendix consists of a table in which, for each group of comparable experiments, are given: (1) the names of the researchers who performed the tests and the reference year, (2) the experiments notation according to the ACI-DAfStb evaluation database, (3) the number of performed tests, (4) the mean values, or clusters centroid location, of the cross-section geometrical parameters (b_w, h, d_s, and A_s), and (5) the quality assessment procedure.

Figure 1. *Method Flowchart*



Figures. 5 and 6 show the scatter plots of the shear capacity V_u of reinforced concrete beams without stirrups belonging, respectively, to group 10 (31 comparable experiments) and group 5 (8 comparable experiments) versus: (a) the width of web b_w, (b) the height of beam h, (c) the shear-to-span ratio a/d, (d) the effective depth d_s, (e) the area of reinforcing steel A_s, (f) the geometric percentage of longitudinal reinforcement ρ_{sw}, (g) the max diameter of aggregates Φ_a, (h) the uniaxial compressive strength of concrete f_{lc}, and (i) the test value for axial tensile strength of concrete $f_{lct,test}$.

Figure 2. *Scatter Plots of the Shear Capacity V_u of Reinforced Concrete Beams without Stirrups Reported in the ACD-DafStb Evaluation Database versus their Main Geometrical Parameters*

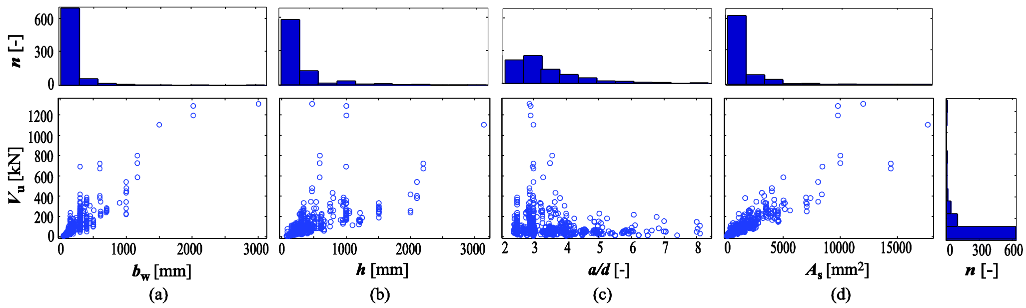
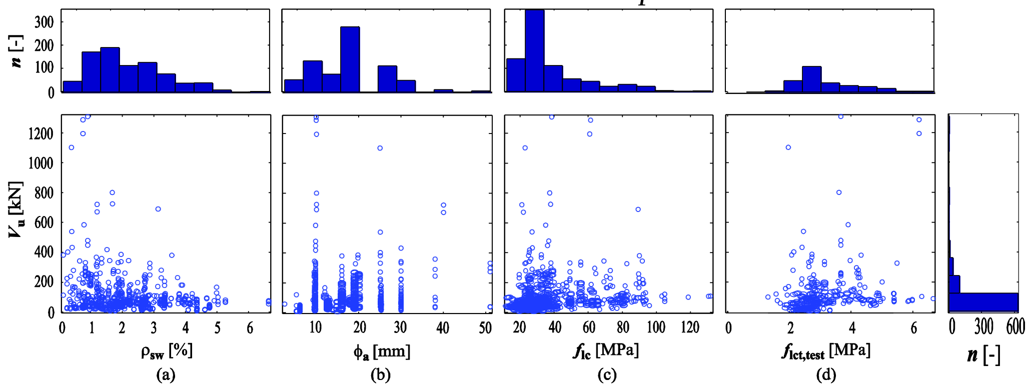


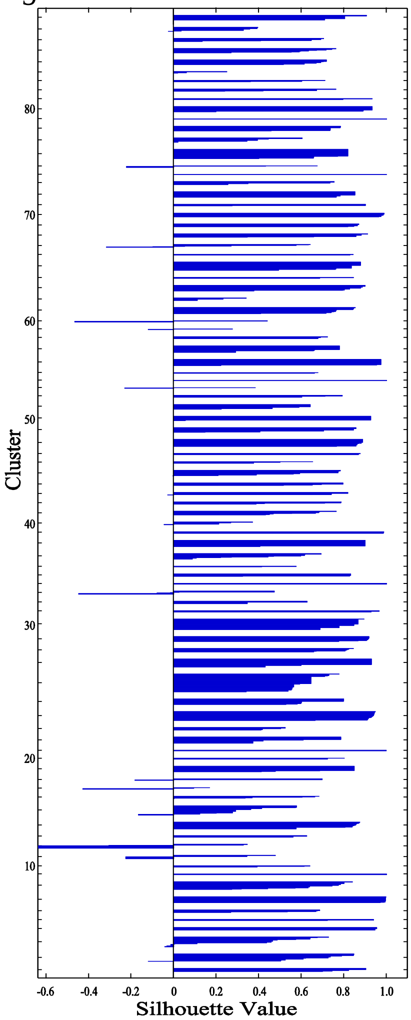
Figure 3. *Scatter Plots of the Shear Capacity Vu of Reinforced Concrete Beams without Stirrups Reported in the ACD-DafStb Evaluation Database versus their Main Mechanical and Concrete Composition Parameters*



Discussion

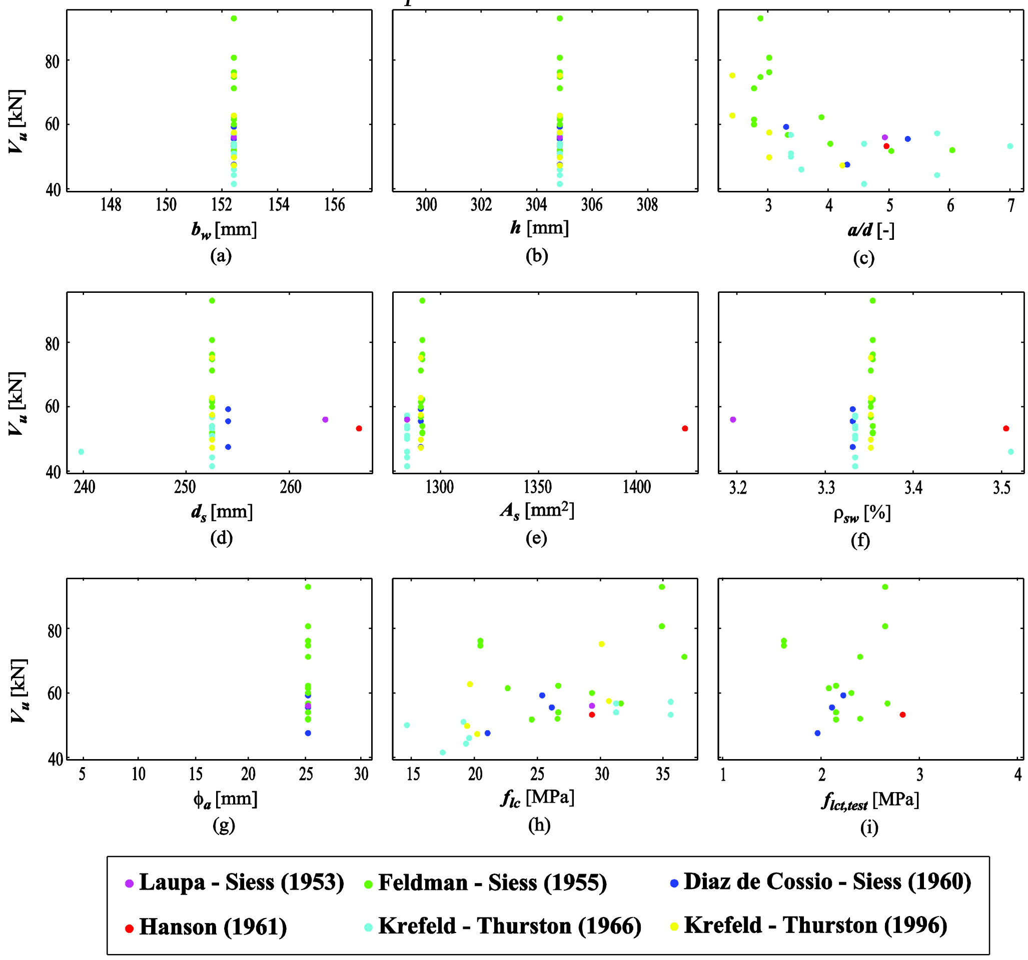
Information extracted from the shear tests database depicts a heterogeneous collection of data that does not readily lend itself to an investigation on the causes to the great shear failure scatter. The scatter plots in Figs. 2 and 3 graphically display these heterogeneities. The first chart highlights that the variation of the considered geometrical parameters is quite large: both the width of the web b_w and the height of the beam h are in the range of from about 50 to about 3100 mm, the shear-to-span ratio a/d varies between 2.4 and about 8, and the area of reinforcing steel A_s goes from a value of approximately 56 to approximately 17650 mm^2. The second graph, instead, depicts the variance of both the main mechanical and concrete composition parameters values: the geometric percentage of longitudinal reinforcement ρ_{sw} varies between about 0.14 to about 6.64 % (going far beyond what is recommended by many international standards such as EN 1992-1-1), the max diameter of aggregates Φ_a is in the range of from 2.5 to 51 mm, the uniaxial compressive strength of concrete f_{lc} goes from approximately 12 to 130 MPa, and the test value for the axial tensile strength of concrete $f_{lct,test}$ is limited to the range of roughly 1.3 – 6.7 MPa. Both the diagrams show a randomness that is much greater that the natural variation of the considered parameters. As one can easily imagine, this huge variation does not help researchers and/or practitioners to understand the target responsible for the great shear failure scatter. Therefore, it becomes necessary to adopt a new method for the selection of comparable experiments.

Figure 4. *Cluster Silhouettes. A High Silhouette Value Indicates that an Object Lies Well within its Assigned Cluster, while a Low Silhouette Value Means that the Object Should be Assigned to Another Cluster*



The ACI-DAfStb evaluation database was then processed by clustering using the k-means algorithm. The cluster silhouettes displayed in Fig. 4 are used to evaluate the relevance of the results and the achieved data repartition. A high silhouette value indicates that an object lies well within its assigned cluster while a low silhouette value means that the object should be assigned to another cluster.

Figure 5. *Scatter Plots of the Shear Capacity V_u of Reinforced Concrete Beams without Stirrups Belonging to Group 10 versus their Main Geometrical, Mechanical and Concrete Composition Parameters*

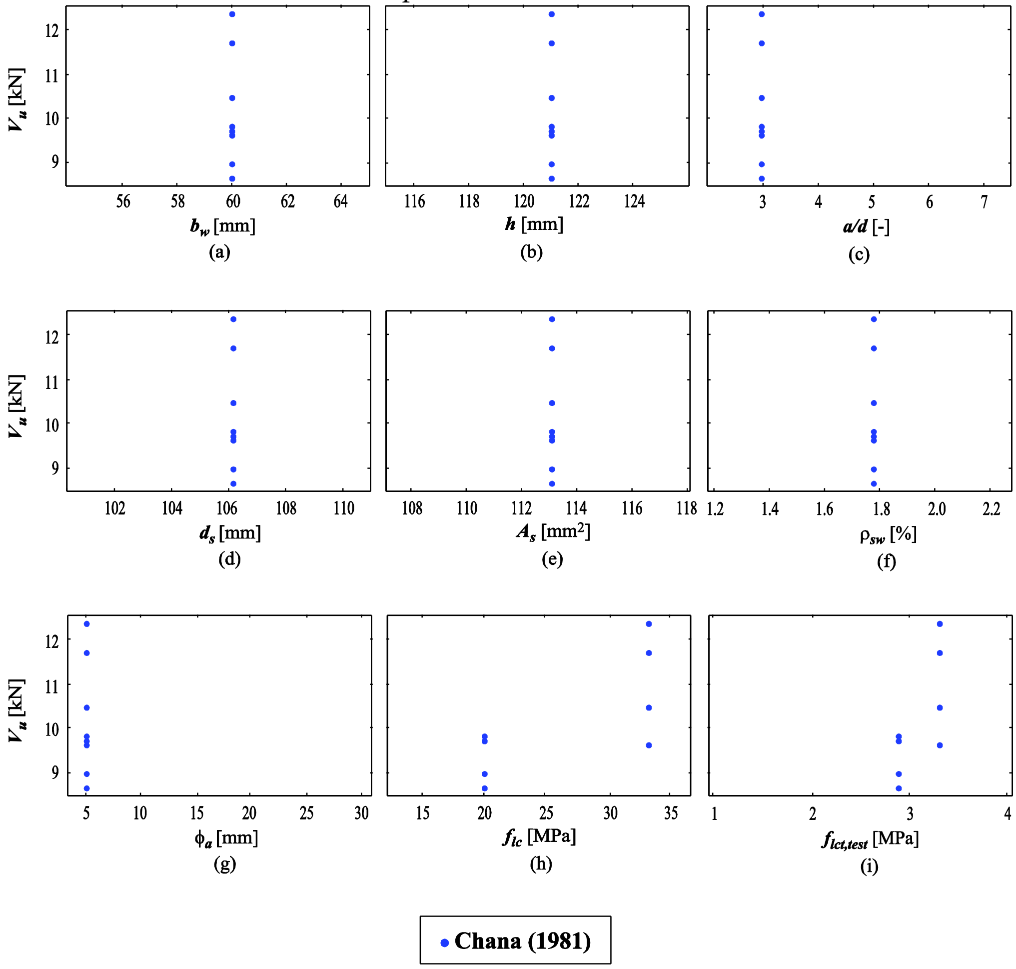


The results obtained by means of the proposed methodology have led to the formation of 13 groups of comparable experiments. Each group is not only structurally distinct but is also un-nested and exclusive, and contains a number of tests between 6 and 43 performed generally by different researchers.

As is shown by both the Appendix and the scatter plots in Figs. 5 and 6, the variation of the considered geometrical parameters is now very small and consistent with the value given by the JCSS Probabilistic Model Code. Consequently, the desired high internal homogeneity for the individuated significant groups of comparable experiments is finally achieved. It is reminded to the reader that the choice of the JCSS Probabilistic Model Code as an external measure for the clusters quality assessment, as previously mentioned, is due to the fact that it gives guidance on the modelling of the random variables in structural engineering.

These groups of reported test results will be of great importance both for the continuation of the authors' research and for other researchers who investigate the causes of the shear failure scatter or develop improved shear design methods.

Figure 6. *Scatter Plots of the Shear Capacity V_u of Reinforced Concrete Beams without Stirrups Belonging to Group 5 versus their Main Geometrical, Mechanical and Concrete Composition Parameters*



Concluding Remarks

In summary, a collection of sets of comparable experiments extracted from the ACI-DAfStb evaluation database of shear tests on slender reinforced concrete beams without stirrups was established. These sets of comparable experiments are intended to be used by researchers who investigate the causes of the shear failure scatter or develop improved shear design methods.

The proposed approach for the selection of the different sets of comparable experiments went through the stepping procedure summarized in Fig. 1 and was based on the data analysis using both multivariate statistical methods and clustering data mining techniques. The criteria to establish the rate of similarity between each set of data were chosen according to the JCSS Probabilistic Model Code.

Finally, it is pointed out that the collection of sets of comparable experiments is provided to interested researchers with this paper or directly by contacting the first author.

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APPENDIX: **Groups of comparable experiments extracted from the ACI-DAfStb evaluation database**

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
1	Swamy; Qureshi (1971)	Swamy_1971_001_M1N3D Swamy_1971_002_M1N3 Swamy_1971_003_M1N3A Swamy_1971_004_M1N3B Swamy_1971_012_M1N8 Swamy_1971_015_M3N4	6	152,4	228,6	171,5	1140,1	0,00	0,00	0,00	0,00
2	Kani (1967)	Kani_1967_018_81 Kani_1967_020_83 Kani_1967_021_84 Kani_1967_023_91 Kani_1967_025_93 Kani_1967_027_95 Kani_1967_028_96 Kani_1967_029_97 Kani_1967_030_98 Kani_1967_031_99	27	153,4	304,8	273,3	1142,7	0,29	0,00	0,31	0,71
	Kani; Huggins; Wittkopp (1979)	KaniHuggins_1979_104_202 KaniHuggins_1979_108_206 KaniHuggins_1979_112_210 KaniHuggins_1979_113_211 KaniHuggins_1979_114_212 KaniHuggins_1979_115_213 KaniHuggins_1979_116_214 KaniHuggins_1979_117_215									

		KaniHuggins_1979_119_709 KaniHuggins_1979_120_666 KaniHuggins_1979_121_675 KaniHuggins_1979_122_718 KaniHuggins_1979_123_742 KaniHuggins_1979_124_744 KaniHuggins_1979_125_746 KaniHuggins_1979_127_502 KaniHuggins_1979_129_504									

APPENDIX (continued 2/6)

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
3	Al-Alusi (1957)	AlAlusi_1957_002_12 AlAlusi_1957_003_11 AlAlusi_1957_005_21 AlAlusi_1957_006_15 AlAlusi_1957_008_10 AlAlusi_1957_009_4 AlAlusi_1957_012_18 AlAlusi_1957_015_7 AlAlusi_1957_016_24 AlAlusi_1957_017_16 AlAlusi_1957_018_17 AlAlusi_1957_019_8 AlAlusi_1957_021_25 AlAlusi_1957_022_9	15	77,1	146,3	125,9	254,1	0,80	0,82	0,41	0,58
	Ruesch; Haugli	Ruesch_1962_001_X									

	(1962)										
4	Laupa; Siess (1953) Hanson (1958) Krefeld; Thurston (1966) Krefeld; Thurston (1996)	Laupa_1953_003_ S3 Hanson1_1958_001_8A-X Hanson1_1958_002_8A Hanson1_1958_003_8B Krefeld_1966_022_4AC Krefeld_1966_028_4CC Krefeld_1966_045_ 4AAC Krefeld_1966_049_ 4AC Krefeld_1966_052_ 4CC Krefeld_1966_059_ 4AAC Krefeld_1966_067_4CC Krefeld_1966_075_OCA Krefeld_1966_076_ OCB Krefeld_1996_022_4AU Krefeld_1996_028_4CU Krefeld_1996_032_4EU Krefeld_1996_048_4AU Krefeld_1996_051_4CU Krefeld_1996_063_4CU Krefeld_1996_067_4EU	20	152,4	304,8	256,5	1013,4	0,00	0,00	0,51	0,00

APPENDIX (continued 3/6)

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s

5	Chana (1981)	Chana_1981_010_4.1a Chana_1981_010_4.1b Chana_1981_011_4.2a Chana_1981_011_4.2b Chana_1981_012_4.3a Chana_1981_012_4.3b Chana_1981_013_4.4a Chana_1981_013_4.4b	8	60,0	121,0	106,0	113,1	0,00	0,00	0,00	0,00
6	Krefeld; Thurston (1966)	Krefeld_1966_004_ 12A2 Krefeld_1966_017_ 20A2 Krefeld_1966_024_ 6AC Krefeld_1966_047_ 6AAC Krefeld_1966_051_ 6AC Krefeld_1966_054_ 6CC Krefeld_1966_057_ 6EC Krefeld_1966_073_PCA Krefeld_1966_074_PCB	11	152,4	304,8	250,2	1583,5	0,00	0,00	0,76	0,00
7	Kani (1967)	Kani_1967_001_40 Kani_1967_002_41 Kani_1967_003_43 Kani_1967_007_47 Kani_1967_008_48 Kani_1967_009_52 Kani_1967_012_55 Kani_1967_013_56 Kani_1967_014_57 Kani_1967_015_58 Kani_1967_016_59 Kani_1967_017_60	12	152,4	152,4	137,5	563,4	0,28	0,00	0,27	0,56

8a	Laupa; Siess (1953) Moody; Viest; Elstner; Hognestad (1954)	Laupa_1953_008_ S11 Moody_1954_025_1 Moody_1954_026_2 Moody_1954_027_3 Moody_1954_028_4	43	152,7	305,2	266,4	771,9	0,20	0,40	0,79	0,57

APPENDIX (continued 4/6)

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
8b	Moody; Viest; Elstner; Hognestad (1954) Krefeld; Thurston (1966)	Moody_1954_029_5 Moody_1954_030_6 Moody_1954_031_7 Moody_1954_033_9 Moody_1954_034_10 Moody_1954_035_11 Moody_1954_036_12 Moody_1954_037_13 Moody_1954_038_14 Moody_1954_039_15 Moody_1954_040_16 Krefeld_1966_014_ 17A2 Krefeld_1966_021_ 3AC Krefeld_1966_027_ 3CC Krefeld_1966_035_ 3GC Krefeld_1966_044_ 3AAC Krefeld_1966_048_ 3AC Krefeld_1966_062_3AC	43	152,7	305,2	266,4	771,9	0,20	0,40	0,79	0,57

Group	Researchers	Experiments Notation	N. of Tests	b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
	Moayer; Regan (1974)	Moayer2_1974_001_P41									
	Kani; Huggins; Wittkopp (1979)	KaniHuggins_1979_058_121									
		KaniHuggins_1979_060_123									
		KaniHuggins_1979_061_124									
		KaniHuggins_1979_062_126									
		KaniHuggins_1979_067_131									
		KaniHuggins_1979_068_132									
		KaniHuggins_1979_076_27									
		KaniHuggins_1979_077_28									
		KaniHuggins_1979_078_29									
		KaniHuggins_1979_079_30									
		KaniHuggins_1979_087_182									
		KaniHuggins_1979_090_186									
		KaniHuggins_1979_095_193									
		KaniHuggins_1979_096_194									
		KaniHuggins_1979_097_195									
	Krefeld; Thurston (1996)	Krefeld_1996_027_3CU									
		Krefeld_1996_031_3EU									
		Krefeld_1996_035_3GU									
		Krefeld_1996_039_3JU									

APPENDIX (continued 5/6)

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
9	Salandra; Ahmad (1989)	Salandra_1989_003_LR-2.59-NS Salandra_1989_004_LR-3.63-NS Salandra_1989_007_HR-2.59-NS	7	101,8	203,5	174,3	253,4	0,05	0,08	0,35	0,00

		Salandra_1989_008_HR-3.63-NS									
	Ahmad; Park; El-Dash (1995)	AhmadPark_1995_007_B7N AhmadPark_1995_015_B7H AhmadPark_1995_016_B8H									
10	Laupa; Siess (1953)	Laupa_1953_004_S4	31	152,4	304,8	253,0	1291,8	0,00	0,00	0,40	0,96
	Feldman; Siess (1955)	Feldman_1955_002_ L-2 Feldman_1955_003_ L-2A Feldman_1955_004_ L-3 Feldman_1955_005_L-4 Feldman_1955_006_ L-5 Feldman_1955_009_L2R Feldman_1955_010_L2aR Feldman_1955_011_L3R Feldman_1955_001_D-1 Feldman_1955_002_D-2 Feldman_1955_003_D-3 Feldman_1955_006_D-6									
	Diaz de Cossio; Siess (1960)	DiazdeCossio_1960_007_A-12 DiazdeCossio_1960_008_A-13 DiazdeCossio_1960_009_A-14									
	Hanson (1961)	Hanson2_1961_004_8B2									
	Krefeld; Thurston (1966)	Krefeld_1966_016_19A2 Krefeld_1966_023_ 5AC Krefeld_1966_029_5CC Krefeld_1966_043_6C Krefeld_1966_046_5AAC Krefeld_1966_050_ 5AC Krefeld_1966_053_ 5CC Krefeld_1966_056_ 5EC Krefeld_1966_060_ 5AAC									
	Krefeld; Thurston	Krefeld_1996_023_5AU									

	(1996)	Krefeld_1996_029_5CU Krefeld_1996_037_5GU Krefeld_1996_049_5AU Krefeld_1996_052_5CU									

APPENDIX (continued 6/6)

Group	Researchers	Experiments Notation	N. of Tests	Cluster Centroid Location for the Basic Parameters				Quality Assessment: $\sigma_{Group}/\sigma_{JCSS} \leq 1$			
				b_w [mm]	h [mm]	d_s [mm]	A_s [mm^2]	b_w	h	d_s	A_s
11	Kim; Park (1994)	KimPark_1994_001_CTL-1 KimPark_1994_002_CTL-2 KimPark_1994_011_A4.5-1 KimPark_1994_012_A4.5-2 KimPark_1994_013_A6.0-1 KimPark_1994_014_A6.0-2	6	170,0	300,0	270,0	860,0	0,00	0,00	0,00	0,00
12	Chana (1981)	Chana_1981_001_2.1a Chana_1981_001_2.1b Chana_1981_002_2.2a Chana_1981_002_2.2b Chana_1981_003_2.3a Chana_1981_003_2.3b	6	203,0	406,0	356,0	1256,6	0,00	0,00	0,00	0,00
13	Rajagopalan; Ferguson (1968) Kani; Huggins; Wittkopp (1979)	Rajagopalan_1968_004_S-3 KaniHuggins_1979_019_143 KaniHuggins_1979_025_149	19	153,1	305,1	271,5	319,3	0,29	0,25	0,22	0,67

KaniHuggins_1979_026_150 KaniHuggins_1979_027_151 KaniHuggins_1979_028_152 KaniHuggins_1979_029_153 KaniHuggins_1979_031_103 KaniHuggins_1979_033_105 KaniHuggins_1979_034_106 KaniHuggins_1979_035_107 KaniHuggins_1979_039_111 KaniHuggins_1979_040_112 KaniHuggins_1979_043_115 KaniHuggins_1979_044_116 KaniHuggins_1979_048_163 KaniHuggins_1979_049_163' KaniHuggins_1979_052_166 KaniHuggins_1979_053_166'	