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Relationship between Ultrasonic Testing and Compressive Strength in Different Age Concrete Structures

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Abstract :*Most Of The Researches Carried Out To Estimate The Compressive Strength Of The Reinforced Concrete Elements Of Our Structures Used To Carry Out Based On Checks With Extraction Of A Large Number Of Test Specimens. Through The Present Investigation 185 Real Cases Of Structural Elements Of Reinforced Concrete Are Studied, By Means Of A Check Based On The Correlation Of Results Between Ultrasonic Velocity (V) And Compressive Strength (R). The Study Is Developed Taking Into Account The Age Of The Structures. Subsequently A Statistical Analysis Is Performed With The Data Obtained And With Them A Clear Scientific Procedure Has Been Defined For The Analysis Of The Two Test Methods And The Necessary Tools To Develop A Complete Structural Evaluation, Correlation Of Results, Which Is Proposed As An Input For Complete The Current Regulations And Facilitate The Procedures Of Structural Expertise, As Well As For The Analysis Of Old Concrete Structures, As The Main Objective Of This Article.*

Keywords*-Compressive Strength, Reinforced Concrete, Structures, Test Tubes, Ultrasonic Testing.*

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I. INTRODUCTION

It Has Already Been Known That Through The Ultrasonic Testing, Possible Discontinuities, Both Superficial And Internal, Are Detected In The Inspected Material [1]. For Its Interpretation, It Is Taken Into Account That Higher Values Of Speed Determine A Greater Density And Compactness Of The Material [2]. The Actual Strength Of The Concrete Is Determined By The Simple Compressive Strength Test. With Both Methods The Structural Check Technique Based On The Correlation Of Results Is Applied, Among Them.

In This Investigation An In-Depth Study Of The Results Obtained With The Existing Methods For The Verification Of Reinforced Concrete Structures Has Been Carried Out. The Aim Is To Deepen The Scientific And Technical Knowledge Of Existing Tools In Order To Set A Reliable Structural Evaluation. Based On The Results Which Have Been Obtained, The Mathematical Models That Relate Both Trials, As Well As The Diagrams, Straight Lines And Regression Curves That Allow To Approach With Confidence The True Values Of (R), According To The Readings Of (V), Have Been Defined.

In Order To Set The State Of The Matter, The Regulations In Force Must Be Remembered [3], Highlighting The Specifications Of The Technical Instruction [4], Regarding The Durability - Useful Life Of The Structure (Related To Age), Are The Variables Which Have Been Studied In This Research.

On The Other Hand, The Origin Of Techniques And Research Methods In Checking Structures In Spain Must Be Dated In The Early Years Of The Sixties, Parallel To The Process Of Drafting And Publishing The First Spanish Standard Of Reinforced And In Mass Concrete: The Concrete Instruction [3], Followed By The Two Digits Corresponding To The Year Of Its Publication.

It Can Also Be Affirmed That There Are No References Of Ordered Data On The Interpretation Of The Correlation Of Results Of These Two Test Techniques (Testing And Ultrasonic Testing), In Reinforced Concrete Structures.

In This Line, After Consulting The Bibliography Published In Other Languages, Which Has Been Accessed, About Experiences In Other Countries Of Our Environment, No In-Depth Correlation Of Results Studies Are Found, With The Studied Variables, Although There Is Some Bibliography [5], Which Analyzes The Results Obtained From These Tests, Handling Other Variables, Such As The Different Sizes Of Test Pieces, Aggregate Typology, Curing Treatments, The Application Of The Theoretical Foundations Of The Ultrasonic Test And The Results Of Some Correlations, Managing These Same Variables, But Of Course, Without The Depth And Breadth Of Information With Which We Have Worked On This Research.

With Regard To The Correlation Between The Results Obtained By The Two Test Methods Proposed (Testing / Ultrasonic Testing), An Orientation Of Results Is Collected, To Evaluate The Quality Of Concrete Structures, Based Exclusively On The Results Of The Ultrasonic Testing.

There Are Many Factors That Influence The Realization And Development Of The Whole Process (From The Type - Quality Of The Starting Material, Initial Dosage Of The Concrete, Type Of The Aggregates, Porosity, Density And Other Variables Of The Hardened Concrete, Up To The Own Techniques And Testing Procedures), Which Generates A Great Possibility Of Dispersion In The Results, Whose Translation To The Simplicity Of The Data Presented In These Tables And Their Great Subjectivity Burden Make Their Interpretation Doubtful, With A Great Risk In Their Use And Concrete Application In Actions - Structural Evaluations, For The Dubious Conclusions That Can Be Reached.

Finally, In Terms Of The State Of The Art, It Is Known That There Is No Mathematical Relationship Between The Strength Of The Concrete And The Speed Of Propagation, But That The Most Appropriate Correlation Must Be Established, Adapted To Each Case And In A More Scientific Way. Therefore, It Is Understandable And Justified In This Article, That Final Results Are Obtained Much More Certain And Much More Reliable, With The Use Of The Presented Tables, Which Will Undoubtedly Facilitate The Interpretation Of Results In The Realization Of Surveys - Studies Of Structural Security, Of Real Cases Of Structures Already Executed, That May Arise In The Future.

II. MATERIALS AND METHODS

For The Development Of The Research We Have Worked With Data Which Have Been Obtained Exclusively From Real Reinforced Concrete Structures, Which Are Located In The Spanish Mediterranean Arc. In Order To Simplify The Nomenclature Used For The Identification Of The Buildings, The Analyzed Structures Have Been Classified, Distinguishing Their Age (More Or Less Than 20 Years) (Tables 1 And 2).

Table 1 Nomenclature For The Identification Of Studied Structures

Age (Years)
E1< 20
E2> 20

Table 2 Classification Of The Types Of Structures According To The Parameters

Type Of Structure	**Age**
A	E1
B	E2
C	E1
D	E2

Regarding The Test Conditions, In Situ Analysis Was Carried Out By Ultrasonic (Ultrasonic Tester) (According To UNE-EN 12504-4 Of 2006), In Different Reinforced Concrete Structures, Obtaining More Than 2000 Data Of Propagation Speed, With Which We Worked In The Statistical Analysis.

Likewise, The Extraction Of Test Specimens Has Been Carried Out, For Later Analysis In The Laboratory, By Means Of The Simple Compressive Strength Test (According To UNE-EN 12504-1 Of 2009), Obtaining 185 Resistance Values. Finally, 5 Outlier Values Were Eliminated And We Worked With 180 Units.

In Order To Discriminate The Study, The Location Of Ultrasonic And Witness Samples, It Was Made By The Analyzed Works, Along The Mediterranean Coast. For Reasons Of Space, The Situation Of Each Of The Works That Are Perfectly Identified In The Corresponding Data Collection, Which Is The Subject Of Another Parallel Investigation, Is Not Detailed. It Is Important To Note That Each Of The Test Specimen Values Has A Unique Ultrasonic Velocity Value Associated With It.

Figure 1 Ultrasonic Testing Process (Left). Moment Of Extraction Of A Test Specimen (Right)

Once All The Necessary Data For The Development Of The Research Were Obtained, The Statistical Treatment Of The Obtained Results Was Carried Out. The Discussion Of The Results Has Also Been Carried Out And Have Been Compared With Other Results Of Different Testing Processes In Existing Structures, Such As Previous Analysis, In The State Of The Art.

III. Results And Discussion

The Table 3 Summarizes The Results Obtained From The Research Process, For The Values Of Compressive Strength (R) (N/Mm^2) And Speed Of Ultrasonic Velocity (V) (M/S).

Table 3 Descriptive Values After The First Treatment Of The Data [6]

DESCRIPTIVE VALUES							
Sample (Subpopulations)	Number Of Values	Mean		Median (Quartile 2)		Standart Deviation	
Measured Variables (R Y V)		R	V	R	V	R	V
Global (Total)	180	16.93	3441	15.40	3535	7.92	548
Age 1 (E1)	62	20.58	3656	21.55	3729	8.84	510
Age 2 (E2)	118	15.01	3329	14.00	3416	6.69	535

These Values Have Been Analyzed For The 180 Studied Elements, Which Are Obtained After The Elimination Of The Different Extreme Values. In This Way, The Original Sample Of The Available Data Is Not Affected, Achieving Great Reliability In The Result To Be Discussed [7].

From The Obtained Results, It Is Interpreted That:

The Average Values Of Resistance For Subgroups Of Age 1 (R = 20.58 N/Mm^2) Are The Highest, Above The Global Average (R = 16.93 N/Mm^2).

The Same Values Of The Age 2 Subgroups (R = 15.01 N/Mm^2) Are Below The Aforementioned Global Average (R = 16.93 N/Mm^2).

The Same Situations Are Reproduced In The Velocity Values (V).

Regarding The Median (Quartile 2 - 50% Of Cases - Values), The Situation Is Mimetically Repeated.

With Respect To The Obtained Standard Deviation, In All Cases Very Close Values Appear, Both In Resistance And In Speed, Which Confirms The Scarce Dispersion Of The Obtained Values.

The Average Values Of Resistance For Age 1 (R = 20.58 N/Mm^2) Are Below The Current Regulatory Limitations, Minimum In An HA-25 (EHE-08), But Above The Minimum Normative Values Set At 175 Kp/Cm2 (17.5 N/Mm^2), In Previous Concrete Instructions.

The Mean Values Of Resistance For Age 2 (R = 15.01 N/Mm^2) Are Well Below The Current Regulatory Requirements And Below The Previous Prescriptions Of R = 17.5 N/Mm^2 (Minimum In Structures Of Reinforced Concrete).

The Correlations (R) Have Been Obtained Between The Values Of Resistance (R) And Speed (V), Which Are Identified In Table 4.

Table 4 Reliability Of Correlations [6]

Sample	R	P-Value
Global (All Structures)	0.677	0.0000
Age1 (E1)	0.833	0.0000
Age2 (E2)	0.608	0.0000
Location 1 (L1)	0.616	0.0000
Location 2 (L2)	0.773	0.0000

Given The P-Value (0.000) In All Cases, The Existence Of A Positive Correlation (At More Speed, More Resistance) And Significant Correlation Is Confirmed, So It Does Not Correspond To Phenomena Due To Chance [7]. Since The Higher The Value Of R, The Better The Correlation Adjustment Is, It Is Confirmed That The Correlation Of R And V In Buildings Of Age 1 (E1) Is More Reliable, Which Corresponds To Buildings Of Younger Age (Type C Buildings). And There Is Less Confidence In Older Buildings With Concrete Structures (Age 2) (Type B Buildings).

In All Cases It Is Clear That The Quadratic Regression Is More Reliable Than The Linear Regression, Given That The Coefficient Of "Explanatory Power" (R2) Is Greater In All Cases, With Respect To The Linear Regression, For Each Of The Studied Sub -Populations [8]. Taking Into Account What Is Stated In The Consulted Bibliography, Other Alternatives Are Proposed, Depending On The Results Of This Investigation. In This Sense, As It Has Been Possible To Confirm, In The National [9] And International Bibliography [3], There

Is A Table (Table 5) Of Correlation Type Values Of Results, For The Classification Of The Quality Of The Concrete In Function Of The Values Of Speed Of Propagation Of Ultrasonic Waves (As It Is Seen, Values Of Compressive Strength Are Not Contemplated), Which Introduces A Clear Factor Of Subjectivityinadequate In This Type Of Research Work.

Table 5 Classification Of Concrete Quality [9]

PROPAGATION SPEED (M/S)	CONCRETE QUALITY
> 4500	EXCELLENT
3500 A 4500	GOOD
3000 A 3500	ACCEPTABLE
2000 A 3000	DEFICIENT
< 2000	VERY DEFICIENT

As A Contribution Of This Study And With A View To A Future Normative Proposal, Table 5 Is Complemented And The Estimated Values Of Average Resistances (R) That Can Be Obtained, Based On The Given Ultrasonic Velocity (V), Are Incorporated For Each Type Of Structure To Be Tested, With Age Variables 1 And 2 (E1 And E2) Corresponding To Buildings Over Or Under 20 Years (Table 6).

Table 6 Definitive Proposal For The Classification Of Concrete [6]

PROPOSAL FOR CLASSIFICATION QUALITY OF CONCRETE CORRELATION OF RESULTS (Velocity And Resistance)					
PROPAGATION SPEED (M/S)	CONCRETE QUALITY (**)	AVERAGE RESISTANCE (N/Mm^2) (Expected Value)			
		A	B	C	D
> 4500	EXCELLENT	> 40	> 32	> 33	> 47
4000 – 4500	VERY GOOD	28 - 40	23 - 32	29 - 33	26 - 47
3500 – 4000	GOOD	18 - 28	17 - 23	24 - 29	13 - 26
3000 – 3500	ACCEPTABLE	11 - 18	14 - 17	19 - 24	6 - 13
2500 – 3000	DOUBTFUL	6 - 11	13 - 14	12 - 19	5 - 6
2000 – 2500	DEFICIENT	5 - 6(*)	15 - 13(*)	4 - 12	11 - 5 (*)
< 2000	VERY DEFICIENT	< 5(*)	< 15(*)	< 4	< 11 (*)

(*) Non-Congruent Values Obtained From The Quadratic Regression Formula.
(**) Denomination Of The Quality Of The Concrete, In Different Scale, For Each Type Of Structure (A, B, C Or D)

IV. CONCLUSION

The Conclusions Derived From This Research, Which May Be Of Direct Application To The Processes Of Structural Checks, Of Special Application In Old Existing Structures, Are Detailed Below.

It Can Be Said That With This Study, A Clear Scientific Procedure Has Been Defined For The Analysis Of The Two Test Methods And The Necessary Tools To Carry Out A Complete Structural Evaluation, To Obtain The Necessary Data And Their Proper Interpretation, Facilitating Sufficient Information To Carry Out A Critical Analysis Of How They Are Developed, Of Their Scope And Fundamentally Of Their Reliability - Level Of Trust, Given That, Their Results Are Going To Suppose The Basic Support For The Future Analysis - Diagnosis - Security Evaluation - Structural And Finally, The Drafting Of The Corresponding Structural Intervention Project (Reinforcement, Repair, Demolition, In Old Structures, Etc.).

The Obtained Results In The Investigation Facilitate The Decision Making In The Evaluation Of The Structural Safety Of The Reinforced Concrete Element. It Shows That The Structural Check Technique And The Systems Of Correlation Of Data Raised, Can Be Considered As A Tool Totally Reliable In The Structural Evaluation, Given That The Results Of The Correlations Confirm Their Aptitude For The Use To Which They Are Intended, Being Able To Provide Reliable Results In An Evaluation – Structural Evaluation For Any Old Structure Of Reinforced Concrete.

As For The Obtained Values Of (R) And (V), The Existence Of A Clear Difference Between The Resistance (R) And Speed (V) Values In The Structures Of Buildings Of Less Than 20 Years Is Confirmed. Age E1 And E2, Respectively, Demonstrating The Highest Quality Concrete And The Most Reliable Correlations In The Structures Of The Youngest Buildings, Which Confirms That In Old Structure Buildings We Must Have More Information, To Objectify Results And Improve The Reliability Of Interpretations.

Through Statistical Analysis, We Confirm Its Great Reliability And Especially The Quadratic Correlations, For The Different Studied Circumstances, And Can Be Directly Applied, As The Case May Be, For Any Structural Check On Existing Old Buildings. It Is Confirmed That The Correlation System That Has Been Reached In This Research Process Is Totally Reliable For Reinforced Concrete Structures, In Any State Of

Conservation And With The Aforementioned Variables Of Age, Of More Or Less Than Twenty Years (E1 And E2).

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