Nondestructive Evaluation of Masonry Materials used in Historic Philippine Structures

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Abstract— **Due to numerous tectonic activities in the Philippines, many old heritage and culturally important structures are in risk of sustaining damage. Unlike their modern counterparts, these structures are mostly made of adobe, clay, lime stones, bricks, blocks, rocks, and the like. These materials are mostly inhomogeneous and contain cracks of variable sizes, especially those with age, as are those used in Philippine structures. Since most of these structures are of cultural significance to the country, their preservation must be given importance. Their preservation would start in an evaluation of the structure in a way that would not damage the structure. As a method of evaluation of these structures, this research aimed to develop a correlation between mechanical properties of materials such as Young's modulus of elasticity and uniaxial compressive strength which are usually determined using destructive tests, and nondestructive parameters, such as ultrasonic pulse velocity and wave attenuation. This method would allow future evaluation of masonry structures in a nondestructive way which would in turn, preserve their historical and cultural worth. Ultrasonic testing was conducted to determine different wave characteristics of different masonry materials commonly used in old Philippine structures. These characteristics were then correlated with material properties obtained from destructive tests of the samples. The correlations obtained between the destructive and non-destructive parameters gave high values of coefficient of determination, resulting in a viable basis for modeling.**

Keywords— *ultrasonic testing; masonry materials; Young's modulus of elasticity; uniaxial compressive strength*

I. Introduction

The Philippines is home to numerous centuries-old Spanish colonial structures such as heritage churches, ancestral homes, and military forts. A large part of these structures are considered national treasures [1] and a number of them are even included in the UNESCO list of World Heritage sites [2]. They can be found in every region of the country, and play an important role in the preservation of its culture and history. That said, most of these structures are made of unreinforced masonry materials like adobe, clay, sea shells, among others; and the age of these structures are probably beyond the design life, making them highly susceptible to natural calamities. This can be seen in the recent 7.2 magnitude earthquake that hit the Visayas region wherein "historic churches dating from the Spanish colonial period suffered the most. Among them is the country's oldest, the 16th-century Basilica of the Holy Child in Cebu, which lost its bell tower." [3] Hence the preservation and possibly, structural retrofitting of these structures should be given importance. This undertaking starts with the structural evaluation of the structures, which cannot be done in a destructive manner since this could degrade the structure and its essence. As an alternative, the study aims to use the results of the ultrasonic tests, namely the wave characteristics such as ultrasonic pulse velocity, frequency, and attenuation, to correlate with different material properties such as compressive strength and Young's modulus of elasticity determined from destructive test results. The results can then be used as a basis for modelling of the structure to determine its performance under different loading conditions.

Ultrasonic technology is based on the principle that ultrasonic wave through material, which travels at a known velocity, is dependent upon the material properties. This method is used for detecting cracking and environmental deterioration as well as estimating the in situ strength [4]. In this method, "an ultrasonic pulser/receiver unit initiates a timing circuit as it sends an electrical signal to the source transducer, which in turn uses an internal piezoelectric crystal to generate a low-energy, high-frequency stress wave. Transducers are coupled to the masonry surface with rubber sheets or gels for maximum energy transmission. The wave travels through the section where the receiving transducer converts the wave energy back to electrical energy." [5] It gives a good picture of the *qualitative* status of a material, and consequently, the structure. That said, this kind of testing does not give direct parameters that can be used to determine material properties such as strength and the modulus of elasticity. A number of studies have tried to correlate **ultrasonic pulse velocity**, which is obtained by dividing the path length of the wave by the transit time taken to traverse the distance, to mechanical properties of different masonry materials such as [6]. These studies suggest power and linear equations, respectively, for the relationship between ultrasonic pulse velocity (UPV) and uniaxial compressive strength (UCS) of masonry materials. Though these can be helpful, the number of types of these materials is large such that site-specific studies are needed for equations to be obtained before they are used in a larger scale of evaluation, especially when used as an estimating substitute to actual destructive tests. One way of strengthening the accuracy of the equations formed is by using multiple NDT parameters in the correlation with the mechanical properties of the material. [7].

Ultrasonic wave attenuation is one parameter that can also be taken from ultrasonic testing of these materials. "This is a measure of the progressive energy loss experienced by the signals as they propagate through the material." [8] For idealized materials, this loss is only due to the spreading of the waves. However, for natural materials such as the differently masonry materials used in Philippine heritage structures, additional loss is incurred due to scattering and absorption. Scattering is the reflection of the waves in directions other than its original one while absorption is the conversion of the wave energy to other forms. [9] This loss is seen in the decrease of the amplitude of the wave as it travels through a path, as expressed by

$$A = A_O e^{-\alpha L} \quad (1)$$

where A is the amplitude of the signal after travelling a path length L, A_O is the unattenuated amplitude (initial amplitude), and α is the attenuation coefficient

The degree of attenuation can then be determined by taking the amount of amplitude loss after travelling a certain path length relative to the input amplitude. Mathematically, this can be expressed as

$$UWA = \frac{A_O - A}{A_O} \times 100\% \quad (2)$$

where UWA is the ultrasonic wave attenuation, A_O is the input amplitude, and A is the amplitude of the signal through the material

This attenuation can be taken based on the maximum positive amplitude (UWAPA), the most negative amplitude (UWANA), or the sum of these two (UWASA).

Evaluation of masonry materials based on material properties will be done using both destructive and non-destructive testing. Non-destructive evaluation will include the study of wave characteristics to obtain a relationship to material properties that such as compressive strength and Young's Modulus determined from destructive tests. If such exists, ultrasonic testing can then be used as a method as evaluation measures of masonry materials, that can then be used to further evaluate the structures from which they come from.

II. METHOD

As outlined in Figure 1, the first step taken was to obtain samples of the material comprising the Manila Cathedral and the San Ignacio Church ruins. These were brought to the laboratory where ultrasonic testing was conducted to determine the wave characteristics through the material. Ultrasonic pulse velocities were directly obtained from the testing while other ultrasonic parameters such as wave attenuations and frequency distributions were determined through further wave processing. Uniaxial compressive testing was then performed to determine the mechanical properties of the material (i.e. Young's modulus of elasticity and uniaxial compressive strength). These parameters were then correlated with the wave characteristics. Different statistical parameters were used to determine best-fit models for the different sets of parameters.

1. Sample Gathering and Preparation

Samples from the Manila Cathedral and the San Ignacio Church Ruins were gathered and transported to the Construction Materials and Structures Laboratory (CoMSLab) at UP Diliman. After letting them rest at room temperature for 2-3 days, the specimens were then cut to size using the diamond blade cutter at the CoMSLab, The samples were cut to a square cross-section with 100 millimeter sides and a height of 150 millimeters to be able to keep a 1:1.5 width to height ratio while keeping the minimum path length for the ultrasonic testing. As an example, the images before and after cutting of the 6th specimen from Manila Cathedral are shown in Figure 2.

2. Ultrasonic Testing

After letting the specimens dry in room temperature for 24 hours, grids were drawn on the surfaces of samples when possible. These consists 10-20 millimeter boxes, depending on the available surface area. To conduct the ultrasonic tests, the Portable Ultrasonic Non-Destructive Indicating Tester (PUNDIT) Lab of the Building Research Service of UP - Diliman was used. It is an ultrasonic tester made by Proceq© that has an interface, two transducers/receivers, and a USB connector that allows control using an accompanying program called Proceq Punditlink It emits an ultrasonic pulse with a 54 kHz frequency. ASTM E494-10, or the *Standard Practice for Measuring Ultrasonic Velocity in Materials,* states that "for maximum accuracy, the highest possible frequency that will present at least two easily distinguishable back echo reflections, and preferably five, shall be used." But since the equipment only emits a 54 kHz pulse, it was used all throughout the study.

After calibrating the equipment and application of petroleum jelly to ensure good contact between the transducers and the surface of the samples, ultrasonic pulses were sent and received at different points along the material. Figure 3 below shows a sample screenshot of the program interface during testing.

3. Uniaxial Compressive Testing

After going through ultrasonic testing, the specimens underwent destructive testing. The Instron© 5982 floor model 100 kN capacity Universal Testing Machine was used. The equipment comes with a computer interface through the program Bluehill© 3 that allows the user to input the specimen geometry so that it instantaneously obtains the stress based on the load applied. The interface also displays the stress-strain curve as the compressive test goes on. For the test itself, ASTM C1314-12, or the Standard Test Method for Compressive Strength of Masonry Prisms, allows any convenient rate of loading to be used as long as the failure happens between 1-2 minutes. Since the equipment allows for numerous parameters to be taken, the compressive stress at yield and the Young's Modulus of Elasticity were selected as those that will be computed and reported in the output file of each test because these are the parameters to be studied in this research. An image that shows an example of the set-up is shown in Figure 4. An image was taken directly after testing. An example of an image of a specimen after testing is shown in Figure 5.

4. Ultrasonic Wave Processing

After all the tests, the ultrasonic waves are processed in order to obtain their frequency spectrums and attenuation characteristics. This was done by extracting the files from the PunditLink program which has output CSV files containing the pertinent data about the ultrasonic wave formed at every point tested. These files were then processed through a MatLab© program that performs a Fast Fourier Transform in order to convert the wave into the frequency domain. The program also determines the maximum positive and negative amplitudes present within each waveform, which will be used to determine the attenuation characteristics and frequency distribution of each wave. This program has a Microsoft Excel file as its summary output file.

III. RESULTS AND DISCUSSION

Correlations between the individual NDT parameters were formed using regression analysis. First, UPV, UWAPA, UWANA, and UWASA were individually correlated to YM and UCS. Then, each attenuation parameter was used as an additional parameter to the UPV equations to improve the strength of the fit.

1. Manila Cathedral Specimens

Originally, a total of six specimens were obtained from the Manila Cathedral, hence the numbering seen and used in documentation. Unfortunately, specimens 2 & 3 were removed because after undergoing destructive testing, the computer accidentally lost power and the data for them were lost. Nevertheless, the four remaining were still used to come up with correlations between the destructive and non-destructive parameters. For the UPV, Figures 6-7 show its relationship with the UCS and YM of the Manila Cathedral Specimens.

Through regression analysis, it was found out that the best fit between UPV and the destructive testing parameters are 2nd degree polynomial relationships. Both cases show very high coefficients of determination (R^2) with values around 0.90. An R^2 value close to unity means that the fit is very good, but caution must be taken because this might be partially due to the limited number of specimens taken. It should also be noted that these equations are obviously empirical and use parameters with respective units (MPa and m/s).

As for the attenuation characteristics, the following graphs show that their relationships with the mechanical properties obtained are somewhat similar to each other. Also, the best fits for all cases that can be obtained were likewise 2nd degree polynomials.

As seen from Figure 8, the correlations between UCS and the ultrasonic wave attenuations are quite good with an average R^2 value of 0.90. On the other hand, the fits between YM and UWA in Figure 9 are slightly poorer, but still considerably well with an average R^2 value of 0.80, with UWAPA having the best fit.

The equations obtained from the regression analysis are given in Table 1. The table also summarizes the R^2 values of the correlation between the individual NDT parameters and the UCS and YM of the Manila Cathedral Specimens. Results show that the best parameters to correlate with UCS in terms of higher coefficient of determination are the UPV and UWANA. For the YM, the UPV tops the list, followed by UWAPA. These equations are of the form

$$DT = \alpha + \beta NDT + \gamma NDT^2 \quad (3)$$

where *DT* is the destructive test parameter *(UCS* or *YM*), *NDT* is the nondestructive parameter used, and *α, β, γ,* are regression coefficients

As seen in previous studies [7], using multiple parameters can help improve the strength of the correlations that are used to predict the compressive strength of the materials. Since UPV is the easiest parameter to determine in actual practice, it is used as the base parameter. The three attenuation parameters were added individually to come up with equations using multiple non-linear regressions. The equations are of the form:

$$DT = \alpha + \beta\, UPV + \gamma\, UPV^2 + \delta\, UWA + \varepsilon\, UWA^2 \quad (4)$$

where *DT* is the destructive test parameter *(UCS* or *YM*), *UPV* is the ultrasonic pulse velocity (m/s), *UWA* is the ultrasonic wave attenuation (*UWAPA, UWANA, UWASA*), and *α, β, γ, δ, ε* are regression coefficients

Tables 2 and 3 show the values of the coefficients for each equation pertaining to the UCS and YM of the Manila Cathedral Specimens, respectively. All equations resulted in an R^2 value equal to unity, mostly because the number of specimens obtained was very little for the degree of correlation to be less than it. As a result, the predicted values for the UCS and YM of each specimen are equal to the actual values.

Unfortunately, no additional specimens from the Manila Cathedral were allowed to be obtained which could have been used to verify the results of the correlations. That said, the validity of the results of the correlations for these specimens have to rely on the coefficient of determination and amount of deviation of the predicted values from the actual ones.

2. San Ignacio Specimens

A total of four samples were acquired from the San Ignacio site. They were relatively small but of roughly similar size such that they were cut to the same dimensions. The fourth specimen obtained was large enough such that two specimens were obtained from it (SI 4a & 4b). Unfortunately, specimen 4a chipped and broke into pieces during cutting because of internal cracks and the additional moisture. Hence, from the four samples, four specimens were obtained. Similar to the Manila Cathedral specimens, the individual NDT parameters were first used to come up with equations to predict the UCS and YM of the samples. The results of this correlation can be seen in Table 4. The equations obtained are of the same form as Equation (3).

The results show that the correlations using UPV have very high R^2 values both for the UCS and the YM cases. As for the ultrasonic wave attenuations, the R^2 values are quite low for both cases, which suggest that attenuation is not as good as a parameter on its own for these set of materials.

Again, as seen from the previous four figures, UPV tends to be a better individual parameter than the three measures of attenuation in terms of correlating with both UCS and YM. This means that less errors are obtained when using the equations that have UPV as its sole parameter than when those with UWA as their independent parameter. As with the Manila Cathedral, correlations considering multiple NDT parameters were obtained. The results of the multiple non-linear regressions done are shown in Tables 5 and 6. The equations are of the same form as that of Equation (4).

Again, due to the limited number of specimens that were obtained, the coefficients of determination of the multiple non-linear regressions all equaled to one. Fortunately, for the case of the San Ignacio materials, an additional sample (SI5) was allowed to be taken. Images of this sample before and after cutting to size are shown in Figure 10. The sample was tested in the same manner as the other ones, and the same parameters were taken. This was done to try to verify the applicability of the correlations obtained for the samples. This tests the different equations obtained and the effects of the difference in size, and essentially the path length of the wave, on the predicted results. The actual compressive strengths and Young's Moduli of this specimen, as well as the values of the NDT parameters are given in Table 7 while the results of the verification are shown in Tables 8.

After applying the NDT parameter values given in Table 7 to the equations to predict the UCS and YM of the two specimens, they were compared to the actual values. These results, shown in Table 8, indicate that the predicted values tend to agree with the experimental results. The prediction using only UPV resulted in a 31% error for the UCS and 15.5% for the YM. The regression analysis showed an R^2 value of 0.92 for the UCS-UPV correlation and 1.00 for the YM-UPV one. Results using attenuation parameters (Tables 2 and 3) also predicted higher errors and this is also observed, on the average, from the results for the said specimen. Lastly, the R^2 values of the equations obtained from multiple regression analyses forecasted that the errors incurred from their use should be less. This forecast came true as seen in the considerable decrease in error incurred when the equations with a combination of NDT parameters were utilized.

IV. CONCLUSIONS

This study inherently aimed to observe and determine the properties of different masonry materials used in historic Philippine structures. As seen from the results, the range of compressive strengths and Young's Moduli of elasticity of the different masonry materials is quite large. This is obviously because of the different conditions and components that make up these materials. As said earlier, differences in the age and environment greatly alter the properties of the materials, and consequently the structures. Some of these structures have undergone fire, earthquake, and even storm damages through their existence which significantly affects the properties of the materials involved.

Correlations were made to determine the relationships of the non-destructive and destructive test parameters. Both the Manila Cathedral and the San Ignacio sets of regression analyses showed very high coefficient of determination (R^2) values, especially using the UPV parameter. This indicated how effective the ultrasonic pulse velocity, which is the main output of ultrasonic testing, is as a gauge used to determine the mechanical properties of the material. Also, when multiple NDT parameters were used in the correlations, higher R^2 values were obtained for both sets of specimens. This proved that the use of additional parameters that also have something to do with the internal structure of the material (i.e. attenuation) helps improve the accuracy of the correlation. That said, caution should be taken in the use of the equations obtained in this research because of the sensitivity of the NDT parameters, especially the attenuation characteristics, to changes in the geometric configuration and testing method used. This was seen in the verification of the results for the San Ignacio samples wherein high errors were incurred in predicting the mechanical properties of the specimen with a different size. Also, the differences between the equations for the Manila Cathedral and San Ignacio samples indicated that individual correlations for different materials are needed in order to determine the relationships between their respective destructive and non-destructive test parameters. Nonetheless, the results of the testing done on specimen SI 5 showed the effectiveness of the method utilized in the research. That test showed how, under careful consideration of geometry and understanding of the parameters, the correlations can be quite useful.
To sum up, this study and its results showed how non-destructive testing, specifically ultrasonic testing, can be used to evaluate different masonry materials both in a qualitative and quantitative sense. It also showed how regression analysis, and the use of multiple NDT parameters, can be used in order to come up with correlations can be used in the field to determine mechanical properties of structures composed of masonry materials without conducting destructive

testing. This is important because of the value of the structures made of these materials to the country's culture and heritage. It provides the initial step towards preservation and if needed, rehabilitation of the structures.

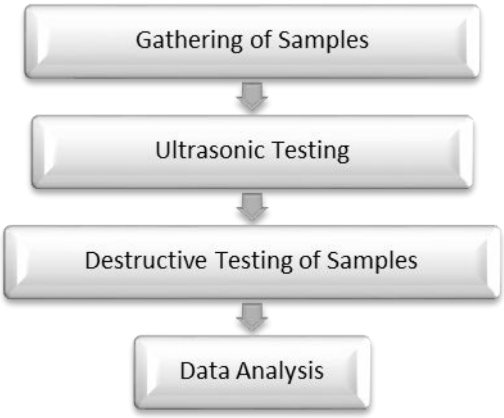

Figure 1. General Methodology Outline of the Study

Figure 2. Images before (left) and after (right) cutting of the MC 6 specimen

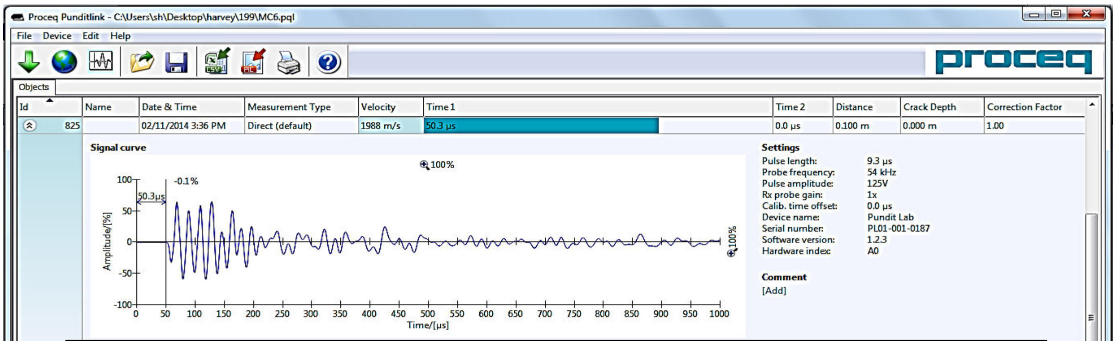

Figure 3. Screenshot of the PunditLink program during ultrasonic testing

Figure 4. Instron 5982 floor model 100 kN capacity Universal Testing Machine with the control panel shown on the upper right.

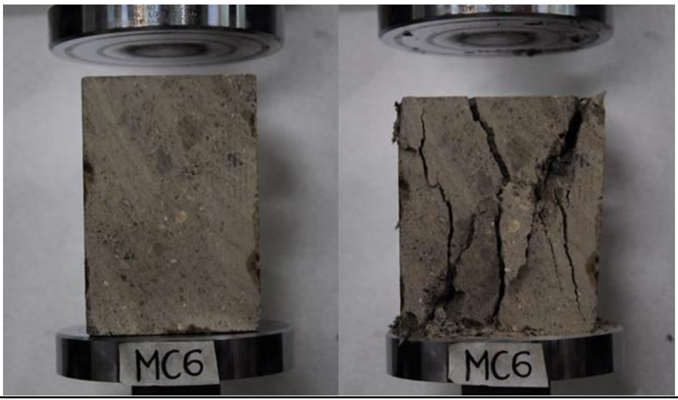

Figure 4. Specimen MC 6 before and after going through destructive testing

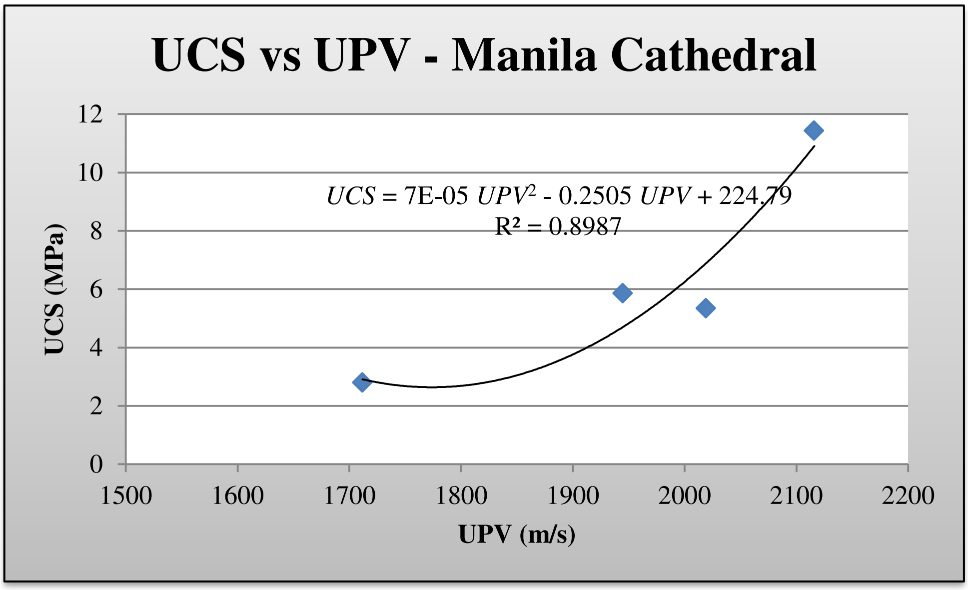

Figure 6. Correlation between UCS and UPV of Manila Cathedral Specimens

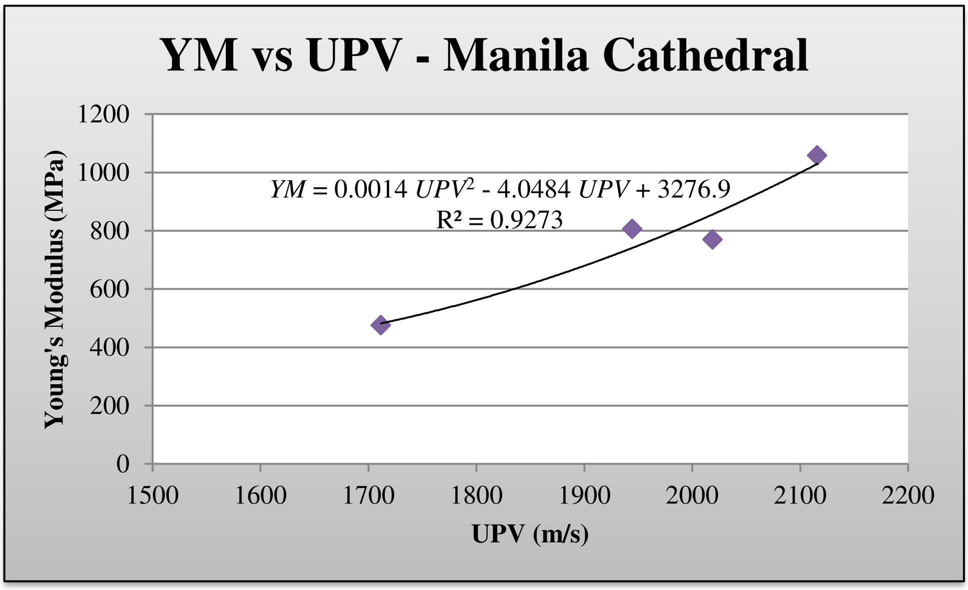

Figure 7. Correlation between UCS and UPV of Manila Cathedral Specimens

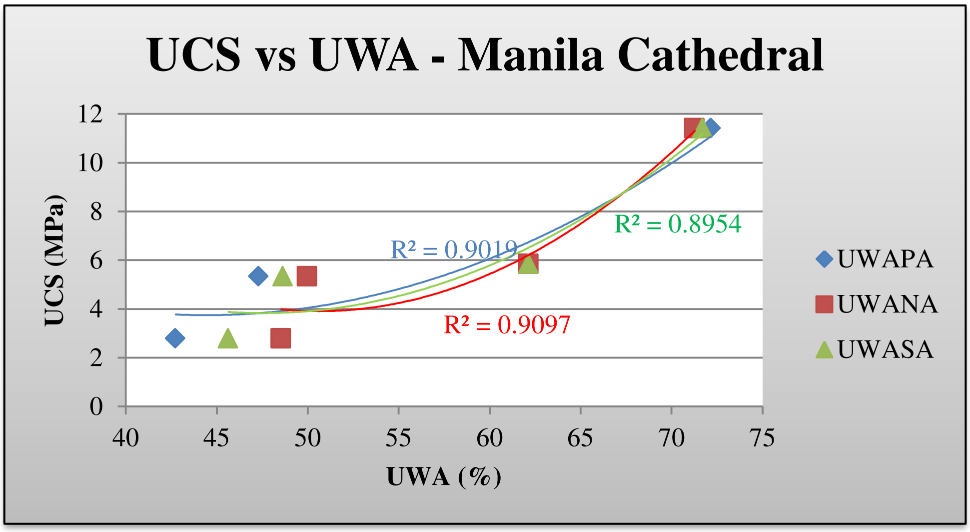

Figure 8. Correlation between UCS and UWA of Manila Cathedral Specimens

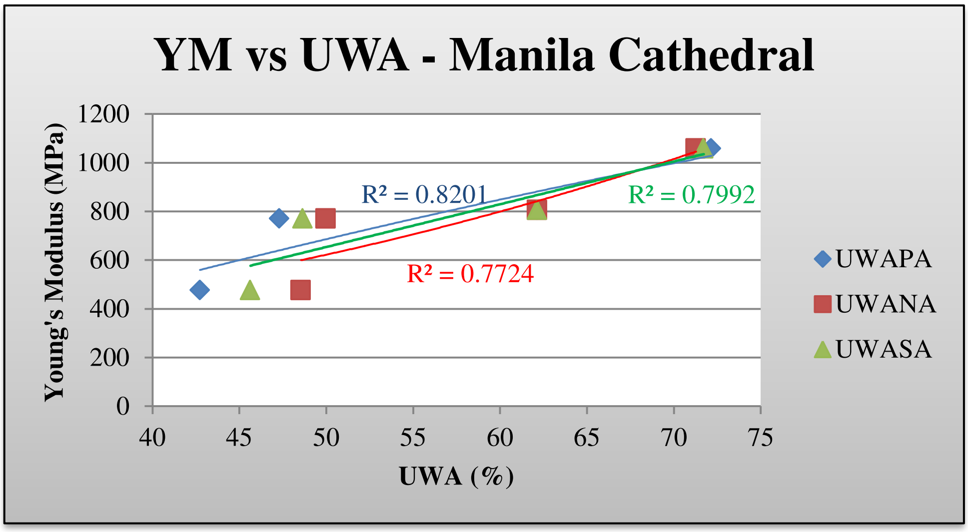

Figure 9. Correlation between YM and UWA of Manila Cathedral Specimens

Figure 10. Images before (left) and after (right) cutting of the SI 5 specimen

Table 1. Regression Coefficients for the Correlations of Individual NDT Parameters with UCS and YM for the MC Specimens

NDT Parameter	***UCS***				***YM***			
	α	*β*	*γ*	R^2	*α*	*β*	*γ*	R^2
UPV	224.79	-0.25	7.06 E-05	*0.90*	3276.87	-4.05	1.41 E-03	*0.93*
UWAPA	22.46	-0.84	9.50 E-03	*0.90*	-324.91	23.53	-6.62 E-02	*0.82*
UWANA	48.33	-1.75	1.73 E-02	*0.91*	323.97	-3.81	1.96 E-01	*0.77*
UWASA	32.19	-1.19	1.26 E-02	*0.90*	-224.24	17.55	1.54 E-04	*0.80*

Table 2. Regression Coefficients for the Correlations of Multiple NDT Parameters with UCS for the MC Specimens

	α	***β***	***γ***	***δ***	***ε***	$\mathbf{R^2}$
UPV - UWAPA	163.07	-0.18	5.03E-05	0	1.16E-03	*1.00*
UPV - UWANA	143.90	-0.16	4.56E-05	0	1.38E-03	*1.00*
UPV - UWASA	154.74	-0.17	4.82E-05	0	1.26E-03	*1.00*

Table 3. Regression Coefficients for the Correlations of Multiple NDT Parameters with YM for the MC Specimens

	α	***β***	***γ***	***δ***	***ε***	$\mathbf{R^2}$
YM - UWAPA	-154.87	-0.19	2.83E-04	0	6.48E-02	*1.00*
YM - UWANA	-1220.75	0.85	1.84E-05	0	7.66E-02	*1.00*
YM- UWASA	-617.73	0.27	1.68E-04	0	7.01E-02	*1.00*

Table 4. Regression Coefficients for the Correlations of Individual NDT Parameters with UCS and YM for the SI Specimens

NDT Parameter	***UCS***				***YM***			
	α	*β*	*γ*	R^2	*α*	*β*	*γ*	R^2
UPV	39.21	-0.05	1.77 E-05	*0.92*	9.38	-1.04	7.66 E-04	*1.00*
UWAPA	11.01	-0.32	2.49 E-03	*0.50*	987.82	-10.33	1.61 E-02	*0.62*
UWANA	3.17	0.16	-1.94 E-03	*0.46*	456.95	26.27	-3.31 E-01	*0.78*
UWASA	3.46	0.11	-1.45 E-03	*0.35*	362.80	27.35	-3.32 E-01	*0.68*

Table 5. Regression Coefficients for the Correlations of Multiple NDT Parameters with UCS for the SI Specimens

	α	*β*	*γ*	*δ*	*ε*	R^2
UPV - UWAPA	-5.75	0	4.1E-06	-0.21	2.22E-03	*1.00*
UPV - UWANA	-12.61	0	5.39E-06	-0.13	1.71E-03	*1.00*
UPV - UWASA	-10.16	0	4.93E-06	-0.16	1.85E-03	*1.00*

Table 6. Regression Coefficients for the Correlations of Multiple NDT Parameters with YM for the SI Specimens

	α	*β*	*γ*	*δ*	*ε*	R^2
UPV - UWAPA	-1014.21	0	4.89E-04	2.25	-1.65E-02	*1.00*
UPV - UWANA	-920.51	0	4.70E-04	1.31	-1.20E-02	*1.00*
UPV - UWASA	-954.54	0	4.77E-04	1.62	-1.33E-02	*1.00*

Table 7. Actual Material Parameters of the SI 5 Specimen

Material	***YM* (MPa)**	***UCS* (MPa)**	***UPV* (m/s)**	***UWAPA* (%)**	***UWANA* (%)**	***UWASA* (%)**
SI 5	487.46	3.72	1677	84.53	83.66	84.09

Table 8. Predicted Material Properties and Percent Error relative to Actual Material Properties of the SI 5 Specimen

NDT Parameter Used	**Predicted *UCS* (MPa)**	**% Error**	**Predicted *YM* (MPa)**	**% Error**
UPV	2.57	*30.92%*	411.91	*15.50%*
UWAPA	1.76	*52.56%*	229.44	*52.93%*
UWANA	2.82	*24.13%*	341.36	*29.97%*
UWASA	2.54	*31.77%*	313.31	*35.73%*
UPV-UWAPA	3.47	*6.59%*	433.65	*11.04%*
UPV-UWANA	3.80	*2.15%*	426.62	*12.48%*
UPV-UWASA	3.73	*0.36%*	428.88	*12.02%*

IV. REFERENCES

[1] National Commission for the Culture and the Arts (NCCA), "Colonial Churches of the Philippines," 2008. [Online]. Available: http://www.ncca.gov.ph/about-culture-and-arts/culture-profile/colonial%20churches/culture-profile-colonial-churches.php. [Accessed 03 February 2014].

[2] United Nations Educational, Scientific and Cultural Organization (UNESCO), "Baroque Churches in the Philippines," 2013. [Online]. Available: http://whc.unesco.org/en/list/677. [Accessed 03 February 2014].

[3] J. I. Andrade and N. Dizon, "Bohol quake 'like 32 Hiroshima bombs'," 16 October 2013. [Online]. Available: http://newsinfo.inquirer.net/507373/bohol-earthquake-strongest-to-hit-visayas-and-mindanao-in-over-20-years. [Accessed 03 February 2014].

[4] UMINHO, "Review on the NDTs for inspecting masonry walls," pp. 1-49, 2006.

[5] M. P. Schuller, "Nondestructive testing and damage assessment of masonry structures," Prog. Struct. gng Mater., no. 5, p. 239–251, 2003.

[6] G. Vasconcelos, P. Lourenc, C. Alves and J. Pamplona, "Ultrasonic evaluation of the physical and mechanical properties of granites," Ultrasonics, no. 48, pp. 453-466, 2008.

[7] M. Flores, "Determination of Ultrasonic Wave Attenuation for Concrete," University of the Philippines Diliman, Quezon City, 2012.

[8] C. Cerillo, A. Jimenez, M. Rufo, J. Paniaguab and F. Pachón, "New contributions to granite characterization by ultrasonic testing," Ultrasonics, vol. 54, no. 1, pp. 156-167, 2014.

[9] Collaboration for Nondestructive Testing, "NDT Resource Center," [Online]. Available: http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/Physics/attenuation.htm. [Accessed 29 March 2014].