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Assessment of Vibration on the Strength of Hardened Concrete for Disaster Mitigation in the Rural Areas

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ABSTRACT

Economic activities are increasingly growing in the rural areas. Examples of these activities are explorations, mining, constructions of roads, traffic and they are man-made activities. These activities generate a lot of ground vibrations. Though the vibration amplitudes may seem small but they build up resulting to large amplitude that can impact negatively on existing structures around. Buildings in rural areas are constructed using local aggregates because they are readily available. The local aggregate materials behave poorly in concrete and sometimes hardly attain design strength. When these buildings are affected by vibrations, some dynamic excitations are generated in the structure which can be very severe and undesirable. This research is to bring to our consciousness the impact vibration may have on the compressive strength of hardened concrete and some possible ways to mitigate against any vibration disaster in the rural areas. In carrying out the study, uncrushed fine and coarse aggregates were used for the experimental work. From the results gotten, it showed that concrete made with local aggregates may not reach their design strength and as such prone to vibration. Therefore, the need for ready-made plans in case of any emergency to minimize losses. A Non-linear regression model that can predict the compressive strength of concrete with vibration effects was developed and it gave a coefficient of determination of 0.948.

Keywords: *Vibration, hardened Concrete, Compressive Strength, Disaster Mitigation, Rural Areas*

Introduction

When vibrations occur in buildings, its effect causes additional strains and stresses on the buildings. These strains are not easy to estimate owing to the nature of vibration (Hashad, 2018). There will be some dynamic excitations generated in the structure which can be severe and undesirable (Smith, 1988). Development is significantly increasing in many aspects towards the rural areas thereby increasing its economic activities too. The aspects include construction of roads (either new or existing), explorations, mining etc. From these activities, heavy machines, plants and some explosives are required to perform the operations. In operating these machines, they generate vibrations that may cause nearby structures to vibrate even down to their foundation of which people in the structures feel and are afraid. These vibrations cause cracks on building walls, disintegration of hardened concrete. Construction operations and industrial machines generate ground motions that can seriously cause damage to buildings. This is because when the forcing or excitation frequency exceed the natural frequency of the structure (Chopra, 2012; Svinkin, 2008), it can lead to resonance.

Concrete is a constructional material that consists of materials like cement, fine aggregates, coarse aggregates, and good water (Neville, 2011; Nemati, 2015). For structures in the rural areas, most concretes are produced using local aggregate materials (uncrushed). This is because they are readily available and with low cost. Many a times, these local aggregates fall short of minimum standards of aggregates for construction thereby producing concrete below design strength (British Standard Institutes, 1992; British Standard Institutes, 1997). Also, very alarming is the ignorance in rural areas on the need to use quality materials when constructing buildings. Some buildings in the urban as well fall in to this problem. These inadequacies are a thing of concern when these buildings are affected with vibrations from some heavy working equipment which might cause structural disintegration, cracks on the structure. The result might also lead to loss of materials that will increase risk to human lives (Smith, 1988; Dawe, 1984), properties or environment itself. Vibrations in structures possess big challenge because when concrete disintegrates, its strength is affected and such buildings are prone to failure (Woods, 1997).

Some researchers have shown that vibration from man-made activities poses great danger to surrounding structures hence the need to minimize damages to buildings. Amick and Gendreau (2000) included frequency content in their work for site-specific assessment of impact of vibrations from construction on sensitive facilities. Hashad, 2012 in his work on the effects of traffic and construction induced vibration on existing buildings found that buildings subjected to construction of traffic vibration need vibration records to ascertain their stress level. The dynamic response of structures especially in the rural areas is necessary to reduce disaster because structures there are sometimes not built to standard. When vibration occurs, buildings undergo dynamic motion. Common features of dynamic excitations show that they generate vibrations in structures upon which they act and these vibrations can be severe and undesirable (Chopra, 2012). The proneness of a structure to dynamic excitation is assessed by the knowledge of the natural frequency of the structure and its associated mode of vibration. This will enable the structural engineer to evaluate dynamic design parameters and to predict the likelihood of resonance (Smith, 1988; Dawe, 1984). It is also necessary to apply principles of dynamics on a structure rather than those of statics in determining structural responses when set in motion. This helps to analyze inertia forces that are absent when static forces are acting on the structure. Most structures in the rural areas are built without dynamic analysis making them vulnerable to disaster.

Disaster mitigation helps to put things in place to protect people or properties from hazards because hazards when they occur can take a society backwards with many losses. It involves the development, improvement and application of practices that will minimize disaster in an area because the soundness and how healthy a building is, is defined at its damage level hence the need to effectively monitor structures as it experiences vibrations (Ceravolo, 2004). Skipp, 1984, focused his review on the classification of sources of vibration generated and instrumentation available for monitoring and measuring vibrations. Chameau et.al 1998, reviewed the standard methods of measuring and analyzing civil engineering vibrations for the influence of vibrations on humans, structures, some sensitive equipment. These researches acknowledged that development activities can generate vibrations which pose danger to surrounding structures.

Consequences of Vibration in Building

The impact of vibration on buildings can depend on the distance from source of vibration, magnitude of construction activities, type of equipment used etc. with the following consequences; there is structural disintegration, the building walls begin to crack and existing cracks are aggravated, they cause fixtures and fittings to damage and eventually fail, vibration present nuisance to occupants of a building, sensitive equipment might be disturbed causing poor reliability, vibration generates extra loads to the structure which might lead to failure.

Most times the vibration activities are very close to existing structures and depending on the intensity of vibration and soil-structure interaction, deformation of the soil is induced (Shrestha, 2009; Hunaidi, 2000). This can affect directly on the structure as it will trigger resonant structural behavior. This paper is focused on the impact of vibrations on compressive strength of hardened concrete from man-made activities which induces vibration and possible ways to reduce disaster in the rural areas. This impact on existing structures deserves serious attention to mitigate against any form of failure as concrete compressive strength is an important aspect in the load carrying capacity of a structure. A model that can predict the vibration effects on concrete compressive strength is developed to reduce tedious laboratory works.

Experimental Methods

The concrete materials used include; Dangote 3x brand of Ordinary Portland Cement gotten from the local market; Local fine aggregates from Obinagu Nike in Enugu East L.G.A, Enugu, with fineness modulus of 3.78. Uncrushed Coarse aggregates also from Obinagu Nike in Enugu East L.G.A, Enugu, Nigeria with maximum aggregate size of 10mm well graded and specific gravity of 2.68. Good water supply from Enugu state water board. The laboratory tests performed include; particle size distribution for the aggregates, specific gravity, slump test, vibration test, compressive strength etc. A mix design ratio of 1:2:4 and w/c of 0.58 were designed for a concrete strength of 25N/mm2. 150mm x 150mm x 150mm cube size was used. A total of 24 concrete cubes were cast and put in the curing tank for the curing process. Two types of concrete cubes were produced and they are; 12 cubes to determine normal concrete strength and 12 concrete cubes to determine vibration effects on concrete strength. The vibration process was performed by the vibrating table used to excite the concrete cubes for enduring testing. These cubes were checked for their 7, 14, 21, 28 days concrete strength using three cubes each. At these ages, the concrete compressive strengths for the normal and vibrated concretes were checked.

Concrete Vibration

Twelve (12) cubes were used for the vibration concrete strength check. These cubes were tested for the 7, 14, 21, 28 days strength. When testing for each of the concrete age, three cubes were removed from the curing tank and kept on a clean floor to allow water drip out for 10 minutes. The weight of these cubes was taken before placing on vibrating shaker and vibrated for 40 minutes. Fig.1 showed the vibrating equipment. The cubes were placed on the table and carefully clamped and guided from falling during the shaking. After vibrating, the weights of the cubes were checked again before finally crushing for the strength using the crushing machine. The interest being the vibration effects on the concrete compressive strength.

Fig.1: Vibrating equipment shaking the concrete cubes.

Model Development

Non-linear regression model was developed to predict the vibrated concrete strength. The vibrated concrete strength is the dependent variable. Normal concrete strength and concrete age are the independent variables, such as;

$$F_{v} = a_1 F_n^{a_2} T^{a_3} \quad 1$$

Where;

$F_v$is vibrated concrete strength (N/mm^2); F_n is normal concrete strength (N/mm^2); T is the concrete age (days); a_1, a_2 ,a_3 are constants.

By applying normal algorithm on both sides of Eq.1, it can be linearised as

$$lnF_v = lna_1 + a_2 lnF_n + a_3\, lnT \quad 2$$

$lnF_v \equiv y, lna_1 \equiv a;\ a_2 \equiv b, lnF_n \equiv x_1, a_3 \equiv c, lnT \equiv x_2$so that,

$$y = a + bx_1 + cx_2 \quad 3$$

By utilizing the experimental data, Eq.3.was calibrated and the constants a, b, c determined thus,

$$F_v = 1.6042 F_n^{0.6667}\, T^{0.1294} \quad 4$$

With Eq.4, the vibrated concrete strength can be predicted and the values for this study presented in Table 3.

Results and Discussion

The results from the laboratory tests that show average values of concrete weight, compressive strength for the normal concrete and vibrated concrete were presented in Table 1 and Table 2. From Table1, there was normal gain in concrete compressive strength as its ages though the design strength of 25N/mm^2 was not achieved at 28 days.

Table 1: showing the laboratory cube results for normal concrete strength.

Concrete Age (Days)	7	14	21	28
Average Cube weight (kg)	7.36	7.55	7.64	7.68
Average Failure load (kN)	375.33	403.33	426.02	487.35
Average Compressive Strength (N/mm^2)	16.59	17.92	18.93	21.66

Table 2: showing laboratory cube results for the vibrated concrete strength.

Concrete Age (Days)	7	14	21	28
Average Cube weight before vibration (kg)	7.35	7.56	7.64	7.71
Average Cube weight after vibration (kg)	7.05	7.21	7.30	7.48
Average Failure load (kN)	308.63	336.34	405.33	442.67
Average Compressive Strength (N/mm^2)	13.72	14.94	17.97	19.66

From Table 1**,** the compressive strength of normal concrete gave 21N/mm^2 at 28 days age as against design strength of 25N/mm^2. The design strength was not achieved which is not good for the structure though result showed progressive gain in strength. This is because compressive strength of concrete has significant effect on load carrying capacity of the building. In the cause of vibration as in Table 2, the concrete weight and strength were reduced. From Table.2, 4.08%, 4.63%, 4.45% and 2.98% reduction in weight were recorded for 7, 14, 21 and 28 days respectively. This loss in mass of concrete might be as a result of falling off of particles of concrete materials during shaking/vibration of the concrete cubes. Though the weight loss decreased as the concrete ages. When local aggregates are used for buildings in the rural areas, vibrations from economic activities seems dangerous no matter the frequency to the buildings as concrete design strength might not be reached. Due to ignorance, lack of knowledge and awareness of building specifications, buildings in rural areas most times unfortunately are built using local aggregates because they are cheap and readily available. These buildings are prone to structural disintegration or even failing to serve its intended purpose. The relationship of vibration effects on concrete strength is presented in Fig.2. showing reduction in the concrete strength.

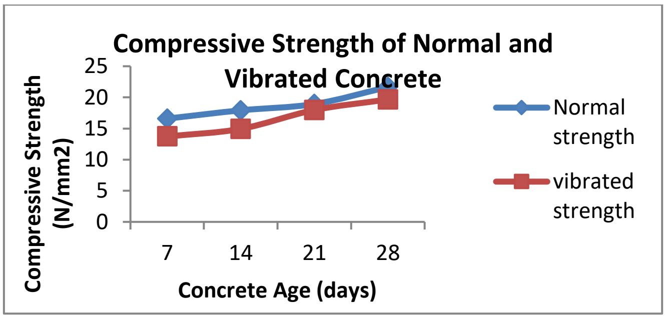

Fig.2. graph showing strength of normal and vibrated concrete

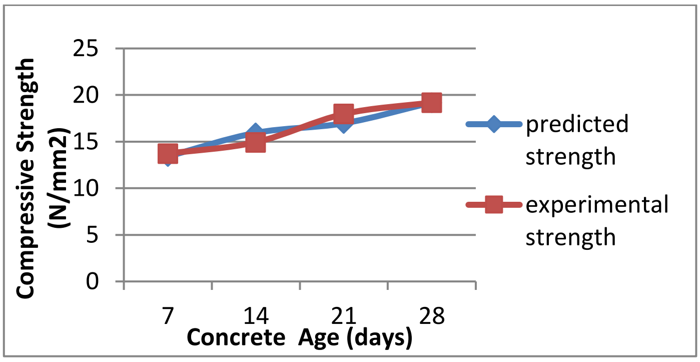

Fig.3. showing graph of the predicted strength and experimental strength

Table.3: Showing the predicted Compressive strength of vibrated concrete

Concrete Age (days)	7	14	21	28
Predicted Concrete Strength (N/mm²)	13.42	15.94	16.97	19.20

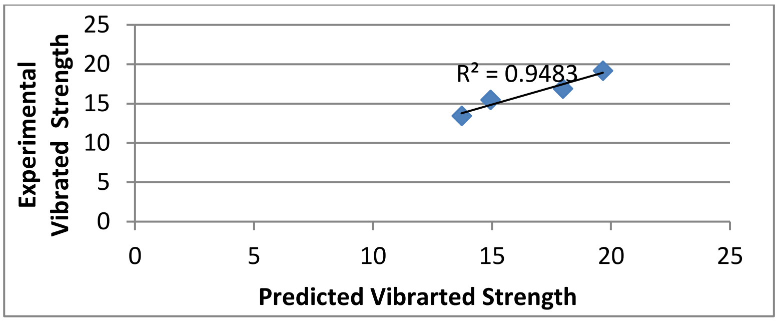

Fig.4 Coefficient of Determination R2 for the Experimental and Predicted Vibrated Concrete Strength

From Fig.4 showing the coefficient of determination (R2), used to determine the degree of linear correlation between laboratory data and model predicted data gave the value R2 = 0.948. The model adequately predicted the experimental data also shown in Fig.3. With the model, it will be easier to check vibration effects on concrete compressive strength with less stress from laboratory works.

POTENTIAL WAYS TO MITIGATE AGAINST VIBRATION HAZARDS

Identifying the building's potential weaknesses and fixing them: check the materials used in producing the concrete especially if local aggregates were used, check if proper bracing was done to the building, check the type of soil and how it behaves, check if the foundation of the building is inadequate.

Creating awareness and education programs on vibration disasters: This will help people to know the dangers of any vibration activity around them and be at alert for changes on their buildings. This is achieved by organizing workshops to the locals, teaching them about vibrations and its associated implications. Then they can insist on designs that include the vibration effects, i.e. dynamic designs and the use of building codes. The local media should be involved and local emergency response teams partnered. Laws that responds and investigates complaints should be put in place.

Identifying potential problems caused by vibration and monitor for damages on building: Some of the damage indicators to constantly look out for include; Windows, doors, stairs are out of level and gaps around them; doors or windows that won't open and close properly; Cracks on the buildings and plaster sliding off; Cracking noise from the building; Sagging or uneven floors; Foundation settling or sinking; Investigate if there is any previous fire on the building. Perform a pre-construction condition survey to be able to manage vibrations from constructions in reducing structural damage i.e. knowing the conditions that exist before the construction.

In-case of severe vibration, move away from the building or protect yourself during the vibration if inside the building and make disaster preparedness plan: these include; Making sure everyone in the household know the hazards involved and its associated risks; Make sure your household knows how to shut off utilities in case of any emergency. This will help to reduce hazards when immediate actions are needed; Make a plan of where to evacuate to if the need arises and what to carry. Here money and mobility is necessary; Make sure that these plans and actions are known to your household.

In the case of on-going construction activities: schedule work to reduce adverse vibration effects, monitor and record vibration from the activities, notify nearby residents that vibration generation activities are imminent.

Conclusion

The experimental study is on the effect of vibration felt in a building even down to its foundation as some construction activities are on-going and this causes fears sometimes. The result showed that structural disintegration and failure may be possible from vibrations. The buildup of these vibrations results to resonance occurrences which causes structural failure. The use of local aggregates in concrete production leaves structures incapacitated. So, the influence of any form of vibration on such structures can be a disaster. Therefore, when such vibration is imminent, proper and controlled disaster measures are to be provided and followed. The model results perfectly predicted the vibration effects on concrete strength and so will give prompt and important information without experimental tests.

Recommendation

It is recommended that since development of an area cannot be stopped and there are existing structures in these areas, and most at times, the structures are not in conformity with building codes, there should be close monitoring of vibration activities in the areas. This should be done by the building occupants and the construction company. Also ensure that disaster preparedness plan is simplified for execution and known by every resident.

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