State of the Art on Retrofitting of Fatigue Damaged Concrete Structures

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Abstract

This article provides a general up to date review of the investigation on performances and resistances of plain and fiber containing concrete structures under periodical loadings of long endurance up to fatigue failure. Structures are almost, under the frequent influences of repeated loadings such as vibrations of rotary machines, sea /river waves, wind, earthquakes and moving vehicles. Long term application of cyclic loading leads to continually slow rate degradation of the structure rigidity leading to fatigue damage. In spite of the dominant usage of concrete, worldwide, as a building material, its fatigue behavior is not straight forward. In addition, this lack of comparison is confronted for fiber fortified concrete. The article also presently a survey of the available techniques for monitoring and measurement of fatigue impressions in concrete structures founded both their impact within the treatise domain and the non-destructive inspection. Those technical means are classified into, at least, two designations, specifically, the monitoring of fatigue induced cracking and the detection of fatigue charged damage. Those techniques parameters, evaluate the changes in the mechanical and physical materials properties during the fatigue endurance, are distantly reviewed in concern of the mechanism creating the change, shortcomings, constraints, etc. The merits, dependency, feasibility, disadvantages and limitations of each technique are assessed and compared to make an index to select the appropriated e technique for fatigues fracture or failure inspection of the type fibered or not of structural concrete

Keywords: Retrofitting, Fatigue, Cyclic Loading

أحدث ما توصلت إليه التكنولوجيا في إعادة تأهيل الهياكل الخرسانية المتضررة بسبب الكلل

شيماء طه ياس، ليث خالد كامل الحديثي

الخلاصة:

تقدم هذه المقالة مراجعة عامة ومحدثة للتحقيق في الأداء والمقاومة للهياكل الخرسانية العادية والمدعومة بالألياف تحت الأحمال الدورية ذات التحمل الطويل حتى فشل الكلال. تتعرض الهياكل تقريبًا للتأثيرات المتكررة للأحمال المتكررة مثل اهتزازات الآلات الدوارة وأمواج البحر / النهر والرياح والزلازل والمركبات المتحركة. يؤدي تطبيق التحميل الدوري على المدى الطويل إلى تدهور بطيء بشكل مستمر لصلابة الهيكل مما يؤدي إلى تلف الكلال. على الرغم من الاستخدام السائد للخرسانة، في جميع أنحاء العالم، كمواد بناء، إلا أن سلوكها الكلالي ليس واضحًا بشكل مباشر. بالإضافة إلى ذلك، يتم مواجهة هذا النقص في المقارنة بالنسبة للخرسانة المدعمة بالألياف. تقدم المقالة أيضًا دراسة استقصائية للتقنيات المتاحة لرصد وقياس انطباعات التعب في الهياكل الخرسانية والتي أسست تأثيرها في مجال الدراسة والفحص غير المدمر. وتصنف هذه الوسائل التقنية، على الأقل، إلى تصنيفين، على وجه التحديد، رصد الكلال الناتج عن التشققات والكشف عن الأضرار المشحونة بالكلال. تتم مراجعة معلمات هذه التقنيات، التي تقيم التغيرات في خواص المواد الميكانيكية والفيزيائية أثناء تحمل التعب، عن بعد فيما يتعلق بآلية إحداث التغيير، وأوجه القصور، والقيود، وما إلى ذلك. المزايا والتبعية والجدوى

والعيوب والقيود لكل تقنية يتم تقييمها ومقارنتها لعمل مؤشر لاختيار التقنية المناسبة لكسر التعب أو فحص الفشل للنوع الليفي أو غير المصنوع من الخرسانة الهيكلية.

1. Introduction

Fatigue phenomenon is often regarded the prime agent causing limit-state failure of RC structures under the action of periodical loading. The concrete fatigue resistance is frequently expressed by the percentage of the monotonic strength that is efficiently withstood under the effect of a specified number of a repeated load cycles [1]. The poor homogeneity of concrete and the extreme cracking in the concrete media attributed to cyclic load subjection brings it to weakening till deterioration thus loading to a significant lowering of the concrete member stiffness followed by fatigue damage due to declining amplitude [2].

The predictions of fatigue endurance of the full variety of concrete types and the wide range of concrete grades were determined by various methods [3-11]. The (S–N) methodology is regarded as the most widely applied approach to assess the concrete fatigue performance subjected to steady cyclic loading and by which the mean fatigue endurance can be predicted [3,12, 13]. By this manner, concrete specimens are cyclically by a wide range of unvarying stress amplitudes till failure, thus loading to the preparation of the curves of stress level versus cycle's number till failure. Among the several, conceptual methodologies frequently used in recent years to assess the fatigue life of structural concrete elements, the approach founded on S–N curves stands as the most widely adopted one in structural practice. Besides, the diagram known as smith/ Goodman diagrams are often used to express the influence of minimum level stress in the cyclic loading for the fatigue of analysis of structural materials of wide range of ductility index values [14]. In addition, a fracture mechanics-base method was recently formulated in the finite element concept [15,16]. Which gives a proper understanding of the mechanical performance. Fatigue phenomenon takes place after the occurrence of local macrostrains under the influence of cyclic influencing forces which produce dislocations of substantially higher densities than those caused by monotonic steady loading [17]. In cellular structures, for example, micro cracking initiate and lead to propagating microcracks under continual cycles of loading [18,19]. And the initiation-followed by propagation of cracks. Is, thereby, considered as the peerless means for evaluating the lagging fatigue endurance related by the features of the fatigue criterion [20,21]. Based on the original features of the fatigue character, it has been recently realized that the detection, measurement and assessment of the fatigue adversity proceeding microcracking creation is quite important.

In spite of the challenging obstacles concerning inspecting, observing and evaluating the accumulating fatigue impressions, several experimental investigations on fatigue damage have been carried out [22]. Even though, evaluation of the of the premature damage under the cyclic loading subjection which proceeds the initiation of micro cracking by a feasible practical indication for the progress of fatigue impression has not been established get. In light of this vision, reviewing of those attempts and their instrumentations from the standpoint of precision, reliability, in versatility restrictions and disadvantages has become of high importance.

The prime content of this article is organized in three distinctly independent respects each regarding an upto date review of the fatigue failure retrofitting for an autonomous field of concrete structures, as follows:

- Performance and Resistance of Normal RC Structures under High Cyclic Loading; an Overview
- Demonstration of Investigations on Fatigue Behavior of Fibrous and High- Performance Concrete
- Recent Techniques of Fatigue Damage Detection and Measurements for Concrete Structures.

2. Performance and Resistance of Normal RC Structures under High Cyclic Loading; an Overview

2.1 General background

Fatigue phenomenon can be expressed in terms irrecoverable and advancing infrastructural alterations in engineering medium due to periodical loading, concerning structural concrete, those alterations generally evolve and accompany the advancing development of microcracks thus giving rise to substantial intensification of permanent deformations. When the cracking becomes of quantitative alterations in the mechanical and physical properties of the structural material. Two types of periodical Fatigue loading causing fatigue exist [23]. The low-cycle and high-cycle applied loads. The low-cycle applied load is represented by small number of loading cycle of high levels stress or deformation, while the high cyclic loading is by applying number cycles at relatively low levels of stress or deformation. Significantly wide spectrum of cycle load causing fatigue which covers even extra – high periodic loading [2].

Analogous to the monotonic loading experimentation, various loading schemes were recently applied in fatigue investigations, which comprise axial, bending and tortional loading schemes, however, the flexural action resulting from cyclic loading is almost the dominant type of fatigue structural action, followed by the compressive action from fatigue loading. Since the commencement of the previous decade, significant attention was payed toward the tensile fatigue performance and resistance of concrete [24-26].

Just at the beginning of incorporating the post linear fracture structural mechanics inelastic analysis of concrete. Thereafter, the influences of compound stresses on the fatigue resistance of structural concrete have been studied by some researchers [27, 28] from which the claim that the fatigue concrete strength compressed triaxially significantly over reaches the corresponding uniaxial compression resistance has been verified.

2.2 Fatigue of plain (not fibered) concrete:

As it originally comprises destitute flaws (i.e. air pores, open voids and close pores frequently occupied by water, bleeding due to poor grading of aggregate and shrinkage created cracks) the structural concrete is considered unable to be heterogeneous material. In accordance, it has become appropriate to demonstrate three distinguished categories [29]. The starting stage is categorized the flaw initiation stage since it concerns the soft locations in the concrete or mortar media, while the second one, categorized "the microcracking stage" as it is featured by the leisurely progressing development of the original flaws to active sizes. Meanwhile, the third stage, categorized "the continuous microcracking stage", represents the onset of formation of an ineligible intensity of instability cracking which is sufficient to bring the concrete or mortar media it fatigue failure [30]. From another standpoint, the initiation stage represents milestone of the steady decrease of the crack growth rate with the cracking development, while the second / final stage is characterized attaining the fatigue failure [31]. In the case of fatigue occurrence due to periodical loading of small frequency and number of cycles, the prime mode of fatigue failure is characterized by forming cracks within mortar the loads to the demonstration of continually cracking networks. On opposite, the fatigue failure taking place under the influence of highly cycled loading is featured by slowly and gradually introducing crack in bond [32]. On contrary to ferrous metals having limit of fatigue, the structural unfibere concrete seems to lacking it. In precise, it has been concluded that any cyclic tensile loading of plain concrete by 2 x 10^6 cycles or less is unable to reveal any fatigue limit at all [33].

2.3 Comparative insight into literature S-N results

The most reliable S versus N relationships for the two spate cases of high – cycle fatigue loading (the uniaxially compressed plain concrete stress state, and the flexurally loaded plain concrete cases) are given by the analytical researchers conducted by the Researchers interiorly indicated in the two graphs [37, 38, 46, 47,48,80,81, 82, 83, 84,88].

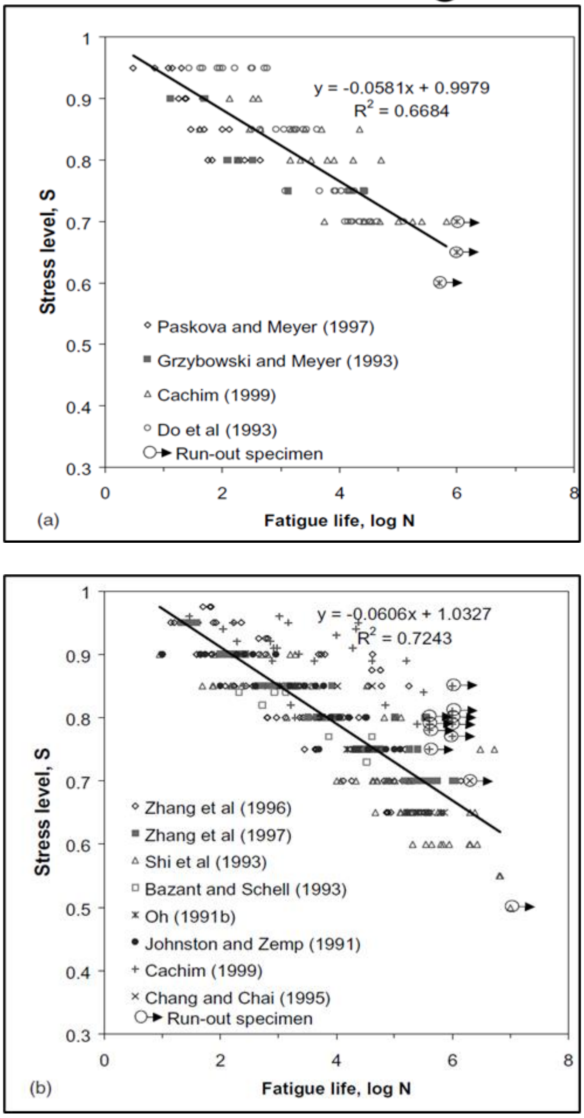

Figure. (1): (a) S–N curve for plain concrete under compression; (b) S–N curve for plain concrete under flexural loading

Inspecting the graphical representation of S versus N relationships (for the two defined action), it is observed that good degrees of agreement and fair correlations between results of those analytical indications are obtained [43].

2.4 Concluding Remarks:

- A substantial quantity of contradicting results and conclusions in the available literature concerning the response of cementations products to cyclic loading (loading to fatigue damage) is generally, detected.
- For the special case of plain concrete, several conflicting trends are also detected.
- It is determined that no accurately –formulated testing disposals for conducting fatigue experimentation has been provided yet. Therefore, the correlation or the extension of the available publicated test outcomes is of insufficient reliability.
- Anyway, fatigue information and results extracted from the large number of experimental published literature has been recently compiled for attempting to set forth fundamental features of the

fatigue behavior to draw a merely uncertain conclusion.

3. Demonstration of Investigations on Fatigue Behavior of Fibrous and High-Performance Concrete

3.1 Prefatory opinion

There are many parameters that influence the performance and resistance of fiber concrete (i.e, reinforced by fiber) to dynamic and cyclic loadings, the primary of which are: confinement of the concrete member, its fiber content, ambient conditions (i.e. humidity, temperature and curing efficiency),frequency and level of the cyclic load, and displacement and loading rates [35].The main activity of fibers in concrete is their crack bridging action by which the propagation and widening of cracks can be partially constrained to some extent, which adds additional resistance and endurance against fatigue, However, excessive amount of fiber may cause the creation of additional flaws tending to lower the fatigue performance and resistance.

3.2 Fatigue response of FRC

Fiber reinforced concrete FRC is commonly used for pavement purposes in floor of industrial buildings, carriage ways in bridges and express ways and tarmacs of airdromes [36], to elevate the endurance against periodical loading.

In general, the steel fibers- when added property to plain concrete can substantially enhance the fatigue resistance in bending action [37-39]. Common applications for FRC include paving applications such as in airports, highways, bridge decks and industrial floors [36], which endure significant cyclic loading during their service life. Within these areas of application, the fatigue characteristics of FRC are important performance and design parameters. However, there seems to be a gulf in the knowledge of the fatigue behavior of FRC in terms of all the influencing variables such as type of loading cycle, strain rates and fiber parameters.

Generally, it has been observed that the addition of steel fibers can significantly improve the bending fatigue performance of concrete members [37-39]. While the plain concrete lacks the fatigue limit (as indicated in sec.2-2), Li and Matsumoto [40]. concluded that the fiber reinforced concrete has a specified limit. Ramakrishan and Lokvik [41] proposed 2 x 10^6 loading cycles for the SFRC to attain its endurance limit. Nevertheless, the ability to bearing loads was proved to be significantly elevated to widening and propagation of crakes [41]. Steel fibers, when added to plain concrete, stand as the prime agent to develop abundant hair cracks to replace far away wide cracks [38]. Moreover, steel fiber renders the FRC of higher ductility under fatigue action [43,44].

Strains exhibited by SFRC just prior to failure are substantially higher than those undergone by un fibered concrete [45]. The fact that steel fibers reveal higher ability of energy dissipation at low levels of stress relative to high levels of stresses was propose by Paskova and Meyer [46]. Cachim [47] elucidated a contradicting statement informs that increasing the steel fibers lengths from 30 mm to 60 mm unexpectedly decreased the fatigue endurance. When the steel fiber volume fraction and length-to-diameter ratio are increased the energy required to widen and propagate cracks in SPRC will increase [48]. While the volume fraction of steel fiber stands as the prime parameter their length-to-diameter ratio and their type seem to add slight enhancement to fatigue performance [37,49]. Referring to the three stages of fatigue behavior of SFRC, it is recommended to govern the development of the flaws in its second phase by inserting condencely distributed and arbitrarily oriented steel fibers [50].

In the uniaxial state of fatigue tensile stress, the resistance fatigue of plain concrete to fatigue crack development and widening is drastically lowered owing to its very poor tensile stress resistance. However, the fatigue endurance in such stressing cases can be substantially improved by using short steel fibers [54]. In specific, the flexural resistance to fatigue action is significantly elevated in SFRC owing to the versatility of steel fibers to constrain crack widening and propagation in addition to tension stressing dispersion [55]. The efficiently uniform dispersion of steel fibers in structural concrete play a vital role in extending the fatigue endurance. In specific, balling phenomenon in the concrete mixing stages (due to inferior fiber distribution) Causes harmful effect on the fatigue endurance [56]. The not impact of the parameters specified above are directly governed by the value of fiber on tent (57]. Finally, silica fume is actually active in assisting the steel fiber in controlling cracking development owing to the silica fume capability of reducing cracking initiated [58].

3.3 Selected review of fatigue experimental work:

The performance of FRC (using polypropylene and steel fibers individually) was studies by Jun and Stang 1998 [59] under flexural repeated loading. They found that the fatigue performance of steel fibered members was improved and that the optimum steel fiber value fraction was around %1.

Kim and Kim (1996) [60] investigated the performance of compressed high strength concrete to withstand fatigue from which they. Concluded that fatigue strain rate of HSC was higher than that of NSC. Meanwhile, endurance shortened with the elevation of concrete resistance, so, NSC exhibited higher fatigue ductility relative to HSC.

From a wide experimental investigation on behavior Cylindrical NSC and HSC samples without and with SFR and CFR under high- cycle cyclic compression.

Cangiano et al. [61] that the role of steel fiber in elevating fatigue resistance and lengthen fatigue endurance was more pronounce than those of carbon fiber. Ballatore and Bocca (1997) [62] found through their investigation on concrete specimens under uniaxial low –cycle compression. That is cyclic loading raised that strain harding and the stiffers. Since that loading reduced the concrete porosity and improved the material compaction. Through their two-third point loading fatigue test of SFRC (beams) Parvez and Foster (2014) [7] elucidated that the fatigue endurance was improved by using steel fibers owing to their capability of decreasing the stress ranges in the steel reinforcing bars.

Makita and Brühwiler (2014) [5] studied the effects of steel fiber orientation and distribution on the fatigue behavior of UHPFRC, where the found that effects these fiber placements on the fatigue behavior disturb in the case of adding steel reinforcing beams.

In his investigation of the influence of the cyclic load frequency on the compressive fatigue performance, Ruiz et al. (2012) [63] found that as the load frequency decreased, the total number of cycles decreased. In addition, they found that under low frequency the steel fiber role in enhancing the fatigue performance became more pronounced.

Finally, the attempt of Al-Azzawwi and Karihaloo in 2014 [64] to replace the earlier expensive brass -coated steel fibers in UHPFRC specimens (in a flexural fatigue test) by an economical and industrially competitive version of steel fiber to produce self-consolidating UHPFRC mix gave positive result regarding the fatigue resistance and endurance.

3.4 Concluding Remarks:

- Several constitution and combination of FRC can be produced to get improved fatigue behavior.
- Numerous probabilities of cyclic loading, sequence, frequency mix constitution and test load arrangements can be proposed to improve the fatigue performance of FRC
- Most of the specialized researchers confirmed the role of steel fibers in enhancing the behavior under cyclic load.
- Quantitatively precise values of the SF role has not been determined yet.
- The endurance limit of FRC is in observable below million cycles.
- Further experimental investigation of frequency above million cycles is recommended.
- Steel fibers slightly improve the fatigue endurance of concrete under compression.
- Meanwhile, steel fiber enhances the fatigue performance under flexure.
- For UHPFRC the fatigue endurance is quit above million cycles.
- Fiber distribution and orientation have prime influence of fatigue performance.
- The higher percentage of damage, the lower is the effectiveness of applied technique.

4. Recent Techniques of Fatigue Damage Detection and Measurements for Concrete Structures; a Brief Survey

4.1 Forwarded statement

Numerous researches in the wide field of fatigue damage and fracture have been published till nowadays, However, no attempt to suggest practical and field procedures for the detection and measurements. In addition to prediction of degradation behind which the fatigue phenomenon stands, before the onset of the first crack initiation,

Means tools and practices preventing the fatigue catastrophic collapse are inherently founded on regressive statistics analysis, assisted by, an accumulative fatigue algorithm, expected to develop further dispersion. Moreover, this argumentation is found in DNVGL-RP [65] and as Keprate and Ratnayake [66]. Thereafter, the microcrack initiation is development, widening and propagate. are still the reliable inherent methodology for predicting the fatigue endurance, since it is originated in the core of the fatigue phenomenon [19] and encompassed by its characteristics [20].

4.2 Crack monitoring

The phenomenon of unfavorite AE resources causes the application of the processing of signals. Such application is observed in practices like "When it arrives of the signal AE, it is inherently demonstrated as being featurable. The experimentation that applies the AE in the site may be inspected and observed in the detection of defects int fluid containers and offshore constructions [67], piers of bridges [68-71],

The concept of ultrasonic pulse/ waves technique is founded upon sending wave of such range of length into the member to be examined. also designated ultrasonic pulse velocity (UPV). The location and the size of the flaw can be precisely obtained from the elapsing time for the ultrasonic pulse transfer and the corresponding wave speed [72]. In the frequently defined by the crack tip being near the surface of the structural concrete member, the signal undergoing diffraction is prone to coincide with the transverse signal in a normalization-based configuration of a pitch- catch that is normally utiliad [74]. The application of high frequency guided waves for the pursuit of the propagation the fatigue-based cracks at holes of bolts and rivets in airplanes was investigated by Masserey and Fromme [74].

4.3 Damage measurements

The procedure for measurement of the damages by electrical resistance evaluation is founded on a essential application similar to the monitoring procedure for cracks. In addition, further paramotors influencing the Specimen resistance are frequently met. Temperature, elongation and necking of cross-section are samples of such parameters. Further variations which may influence the measurement accuracy have either to be discarded or taken into consideration [75]. A methodology for the inspection of damage and allocation based on the utilization of several electrodes, and an algorithm to be applied as equipotential line bake projection were proposed and designed by Mao et al. [76],

The technology of thermometers is established on the concept of absorption of hysteresis energy during high cycle fatigue occurrence in which more than three quarters of the energy is supposed for dissipation in to the environment as thermal energy, leaving the small amount of the remain energy to increase it's potential [77]. The determination of the fatigue, endurance and history by the utility of energy dissipation to heat was investigated and verified by Some researchers [78]. Meanwhile, the vacancies development through Strain hardening and fatigue endurance was highlighted by other researchers [79].

4.4 Concluding remarks

- To a conduct a signal a specimen test, then obtain it is resulting that specimen ought to be a fatigue examined and also continually being a monitored during the fatigue endurance test. Hence, it is a time dissipating procedure.
- The impact of some specified test a controlling parameter and unfortunately, unavoidable. This issue further makes the experimental program rather a complicated.
- Validation of the methods like, for example variable Amplitude loading the (VAL) should be carried out.
- Both the XRD and the thermometric methods attained reliable accuracy to evaluate the remaining fatigue life.
- Although micro alternative within the fatigue endurance may be measurable. They are incapable of defining neither the remaining not the consumed endurance of the fatigue.
- The crack detection and its measurements stand as peerless normal practice of the estimation of the remaining fatigue life.

For measurements of fatigue damage, the adopted parameters are directly related to the progress of the fatigue microstructural damage.

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