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Ductility Ratio and Toughness Index of Reinforced Concrete Slabs Subjected to High Temperature

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Abstract

Ductility ratio and toughness index were studied for two – way reinforced concrete slabs subjected to high temperature and cooling . . Empirical equations were developed to predict the ductility ratio and toughness index (in terms of temperature and reinforced ratio) of such slabs under uniformly distributed load . These proposed equation gave good agreement when compared with the experimental results, with a correlation factor for ductility ratio and toughness index of 0.94 and 0.95 ,respectively .

Keywords: – *slabs, ductility ratio, toughness index, high temperature, two-way slab, ductility, reinforced concrete.*

Introduction

There are several important considerations, which can affect the performance of concrete structures. Concrete members are designed so that the reinforcing governs their capacity will exhibit ductility behavior. Ductility is the ability of a structure to undergo increasing deformation beyond yield stresses while still sustaining gravity and other loads [1]. In the extreme event of a structure being loaded to failure, it should be capable of undergoing large deflections at near – maximum load carrying capacity. This may save lives by giving warning of failure and prevent catastrophic collapse.

Where energy must be absorbed as in blasts and earthquakes (seismic loading), a very important consideration is the toughness and ductility of the structure. . Reinforced concrete members may be exposed to elevated temperatures by accidental fire in buildings, also in some industrial installations and in nuclear reactor pressure vessels [2], so it is important to know its ductility.

Several investigations [3, 4, 5] have shown deterioration in structural properties of concrete and steel under high temperature, the degree of deterioration is influenced by many variables suchas

Composition of combustible materials in the compartment, ventilation effects will cause variations in the rate of heat generated and the peak temperature, heat transmission which occurs through structural cross – section as well as the state of structural element (simply supported or fixed at the end of member).

Nizamuddin and Bresler [6] studied analytical predictions of the displacements and stress histories for reinforced concrete slabs in fire. Lie and Leir [7] studied the influence of the various factors that affect temperature history and thermal properties of materials in fire exposed concrete slabs. Shirley et. al. [8] showed fundamental information on the behavior of high strength concrete slabs at elevated temperatures using realistic test specimens, the tests were based on the criteria for temperature rise of the unexposed surface. Ellingwood [9] showed difference fire – ratings behaves during an actual fire on concrete slabs.

Tassios and Chronopoulos [10] studied the structural response of reinforced concrete elements during fire, using non – linear temperature profiles through the depth exposed elements.

More studies [2, 3, 5, 6, 7, 8, 9, 10] deal with performance of member at elevated temperature. While there were limited researches about behavior of members after they have been subjected to high temperature.

After the concrete member is subjected to high temperature it may undergo large deformation. Decreasing the strength of installed material (concrete and steel). So to use the structure again after ending of the fire, it may be important to find out the ductility and toughness of members.

The ductility ratio represents the ratio of deformation at ultimate load to deformation at first yield. On the other hand toughness is represented and measured by the area under the load – deflection curves [11, 12]. Toughness index is the ratio of the area of load – deflection curve subjected to elevated temperature to the area of load – deflection curve of control specimen (at normal temperature).

The main purpose of this paper is to study the effect of temperature on ductility and toughness of concrete slabs reinforced with different steel ratio .

The study deals with residual ductility, toughness of reinforced concrete slabs after they have been exposed to high temperature and cooling (not during high temperature there are differences in response between the above two states).

Such knowledge may be useful to know, the state of structure after ending of the accident fire, and ability to reuse the structure , because ductility could be considered as part of the safety provisions.

Experimental Data

Ductility ratio and toughness index were calculated from experimental results (18 slabs) of Ref. [13], convering the behavior of reinforced concrete slabs. Both faces of the slabs (top and bottom) were subjected at the same time to ultimate high temperatures of 25, 300, 400, 500, 600 & 700 °C for a period of one hour in a furance type " Wenger " , (maximum temperature 1400 °C).

The slabs (600 * 600 * 40 mm) were cooled to normal temperature gradually then the simply supported slabs were tested under uniform distributed load until failure. The load – deflection curves for tested slabs are shown in Fig. (1) (Ref.[13]).

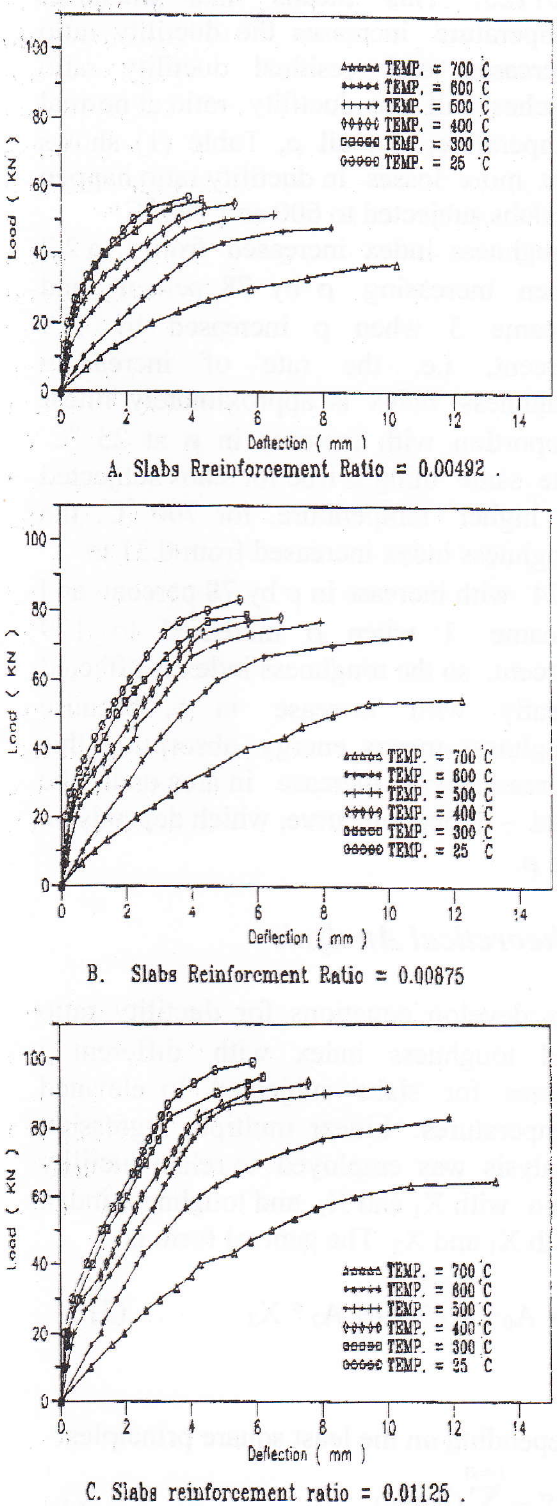

Fig.(1) Effecte of temperature on concrete slabs reinforced with different reinforcement ratio (A , B , C) Ref. [13]

Ductility ratio and toughness index were calculated based on data from Ref. (13). Ductility ratio is the ratio of deformation at ultimate load to deformation at first yield and toughness index is the ratio of area under load – deflection curve of slabs subjected to high temperature of 300, 400, 500, 600 and 700 °C to the area under the load – deflection of slabs at normal temperature.

To study the effect of temperature and amount of reinforcement on the ductility ratio and toughness index of reinforced concrete slabs, two variables were taken into account as follows:

$$X_1 = \rho \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$X_2 = T \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where

ρ = reinforcement ratio ,percent .

T = Temperature in , °C .

Values of X_1 and X_2 of all tested slabs are given in Table (1). Ductility ratio and toughness index with X_1 and X_2 are shown in Figs. (2) and (3).

These figures show the deterioration in ductility ratio and toughness index with increasing exposed temperature. At normal temperature with increasing ρ from 0.00492 to 0.00875 (i.e. 78 percent), the ductility ratio increases by 5 percent. When increasing ρ from 0.00492 to 0.01125 (i.e. 129 percent), the ductility ratio increases by 7.5 percent.

When slabs are subjected to 700 °C, increasing ρ by 78 percent the ductility ratio increases by 28 percent, and increasing ρ by 129 percent the ductility ratio increases by 25 percent, this indicates that the rate of increasing in ductility ratio decreases with increasing ρ, so increasing ρ is insufficient for increasing the ductility in slabs, (an increase in tension steel content decrease the ductility, because the deformation at first yield is increased and deformation at ultimate decreases [11], in practice for reinforced concrete slabs at normal temperature and after they were subjected to high temperatures. There were differences from those mentioned in Ref. (11).

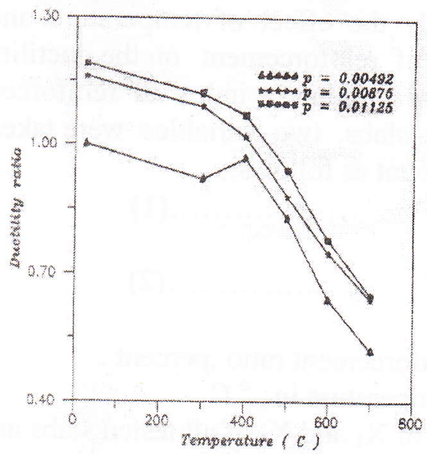

Fig.(2) Relaion between Temperature & Ductility ratio of concrete slabs subjected to high temperature .

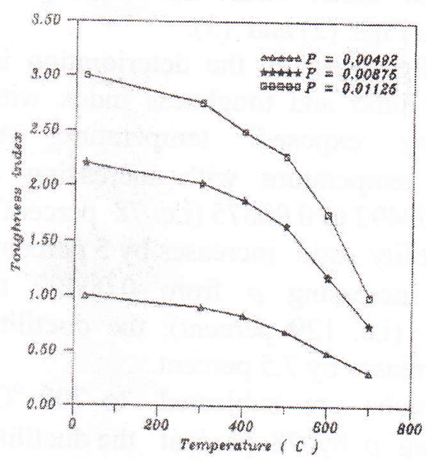

Fig.(3) Relation between temperature & toughness of con slabs subjected to high temperatures.

After slabs were subjected to 700 °C, Table (1), the residual ductility became 47 percent for ρ equal to 0.00492, and 55 percent for ρ equal to 0.00875 and 0.01125. This means that whenever temperature increases the ductility ratio decreases and residual ductility ratio reaches half the ductility ratio at normal temperature, for all ρ, Table (1) shows that more losses in ductility ratio happen in slabs subjected to 600 and 700 °C.

Toughness index increased from 1 to 2.2 when increasing ρ by 78 percent, and became 3 when ρ increased by 129 percent, i.e. the rate of increasing toughness index is approximately linear proportion with increase in ρ at 25 °C. The same thing is true for slabs subjected to higher temperature, for 700 °C, the toughness index increased from 0.31 to 0.74 with increase in ρ by 78 percent, and became 1 when ρ increased to 129 percent, so the toughness index is affected greatly with increase in ρ, because toughness means energy absorption, this increases with increase in area under the load – deflection curve, which depends on the ρ.

Theoretical Analysis

To develop equations for ductility ratio and toughness index with different ρ values for slabs subjected to elevated temperatures. Linear multiple regression analysis was employed to relate ductility ratio with X_1 and X_2, and toughness index with X_1 and X_2. The general form is:

$$Y = A_0 + A_1 * X_1 + A_2 * X_2 \qquad \ldots(3)$$

Depending on the least square principles:

$$S = \sum_{i=1}^{i=n} (Y - y) \qquad \ldots\ldots(4)$$

$S = \sum (A_0 + A_1 * X_1 + A_2 * X_2 - y) \cdot\cdot$
.....(5)

Where:
A_0, A_1, A_2: Coefficients
S: Sum of errors (error function).
Y: Value given by the proposed equation.
y: Observed value.
n: Number of Data point.

Minimizing the error function with respect to (A_0, A_1, A_2) as shown below:

$\partial S / \partial A_0 = 0$ ....(6)

$\partial S / \partial A_1 = 0$ ....(7)

$\partial S / \partial A_2 = 0$ ....(8)

Equations (6), (7) and (8) can be written in matrix form as follows:

A a = b ....(9)

Where A is coefficient matrix taken the following form:

$$A = \begin{pmatrix} N & \sum X_1 & \sum X_2 \\ \sum X_1 & \sum X_1 & \sum X_1 . X_2 \\ \sum X_2 & \sum X_1 . \sum X_2 & \sum X_2 \end{pmatrix}$$

$$\text{a is unknown vector} = \begin{pmatrix} A_0 \\ A_1 \\ A_2 \end{pmatrix}$$

$$\text{b is known vector} = \begin{pmatrix} \sum y \\ \sum X_1 . y \\ \sum X_2 . y \end{pmatrix}$$

A personal computer was used to determine the values of the coefficients A_0, A_1, and A_2. The best empirical equations:

Ductility ratio = $0.998 - 7.66 * 10^{-4} * T + 26.17 * \rho$ .....(10)

Toughness index = $0.353 - 1.966 * 10^{-3} * T + 238.4 * \rho$ ....(11)

Equations (10) and (11) gives results which are in good agreement with those obtained from tests, see Table (1), Figs. (4) and (5), the correlation factor (r) between theoretical and experimental results are equal to 0.94 and 0.95 for ductility ratio and toughness index respectively.

To find out just the effect of reinforcement on the ductility ratio and toughness index separately, the following equations are determined:

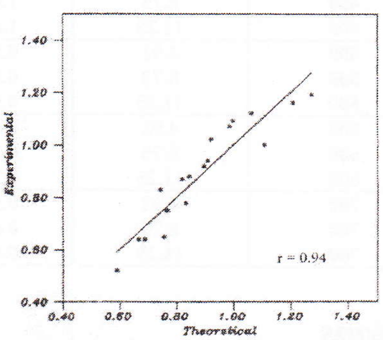

Fig.(4) Relation ship between experimental & theoretical of ductility ratio .

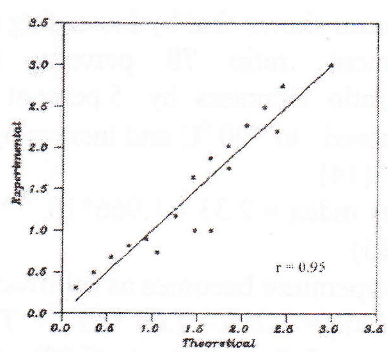

Fig.(5) Relation ship between experimental & theoretioc of toughness index .

Ductility ratio = $0.6754 + 26.17 * \rho$ ....(12)

Toughness index = $- 0.4745 + 238.4 * \rho$ . ...(13)

With a correlation factors (0.79) and (0.42) for the ductility ratio and toughness index respectively.
Also to find out the effect of temperatures on ductility ratio and toughness index separately, the general equation depending of reinforcement ratio is not sufficient for increasing ductility.

Table (1), Ductility ratio and toughness index of ,tested slabs [6] , and of Eqs .(10), and(11).

No.	Temperature °C	Rein. Ratio $\rho * 10^{-3}$	Ductility Ratio Experi.	Toughness Index Experi.	Duct. Ratio Theore. Eq. (10)	Tough. Ind. Theore. Eq.(11)
S11	25	4.92	1.107	1	1.107	1.477
S12	25	8.75	1.16	2.2	1.21	2.39
S13	25	11.25	1.19	3	1.272	2.99
S21	300	4.92	0.92	0.9	0.897	0.936
S22	300	8.75	1.09	2	0.997	1.85
S23	300	11.25	1.12	2.75	1.062	2.45
S31	400	4.92	0.87	0.82	0.82	0.74
S32	400	8.75	1.02	1.87	0.92	1.65
S33	400	11.25	1.07	2.49	0.986	2.25
S41	500	4.92	0.83	0.68	0.743	0.543
S42	500	8.75	0.88	1.64	0.844	1.456
S43	500	11.25	0.94	2.27	0.909	2.05
S51	600	4.92	0.64	0.49	0.667	0.346
S52	600	8.75	0.75	1.18	0.767	1.26
S53	600	11.25	0.78	1.75	0.833	1.86
S61	700	4.92	0.52	0.31	0.59	0.15
S62	700	8.75	0.64	0.74	0.69	1.06
S63	700	11.25	0.65	1.0	0.756	0.7

Conclusions

The main conclusions of this investigation are:

1- It has been shown that by increasing the reinforcement ratio 78 percent, the ductility ratio increases by 5 percent for slabs exposed to 700 °C and increasing ρ ………….(14)

Toughness index = $2.33 - 1.966*10^{-3}*T$. ……….(15)

just on temperature becomes as follows:

Ductility ratio = $1.215 - 7.66*10^{-4}*T$.

With a correlation factors (0.87) and (0.57) for both ductility ratio and toughness index respectively, it has been concluded that equations (14) and (15) give better results than equations (12) and (13).

to 129 percent, ductility ratio increases by 7.5 percent. This indicates that increasing

2- For slabs subjected to 700 °C, whenever ρ increases by 78 percent, toughness index increases from 0.31 to 0.74, and increasing ρ by 129 percent toughness index increases from 0.31 to 1.0. This shows that reinforcement ratio has significant effect on increasing toughness (at the same temperature).

3- For reinforced concrete slabs more the losses in ductility happen at slabs subjected to 600 and 700 °C. For slabs subjected to 700 °C the loss reaches half the ductility at normal temperature.

4- The loss in toughness index at 700 °C reaches one third the toughness index at normal temperature. It is concluded that toughness index is more sensitive to temperature than ductility.

5- The present empirical equations provide residual ductility ratio and toughness index for reinforced concrete slabs after these slabs are subjected to any state of heating and different reinforcement ratio. Results from these equations show good agreement with the experimental results

Practical Applications

The empirical equations (10) and (11) described here can be used to relate ductility ratio and toughness index for any exposed temperature and different reinforcement ratio to levels of structural failure in reinforced concrete slabs.

The aim is to limit damage due to fire. These equations can be further refined, taking into account more variables to generalize these equations to make them more practicals. T:ey will be used in the repair of fire – damaged structures, to assess structural damage caused by severe fire.

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نەرمیو توندی بنمیچە کونکریتی‌یەکان کەخراونەتە ژێر گەرمی بەرز

د.عمر قرەنی عزیز و د.احمد هدایت محمد

بەشی ئەندازیاری شارستانی / کۆلیژی ئەندازیاری/ زانکۆی سەلاحەددین / هەرێمی کوردستانی - عێراق

پوختە

لەم لیکولینەوەدا باس لە نەرمی وتوندی بنمێچی کونکریتی شیشدارکراو پاش خستنە بەر گەرمی بەرز وسارکردنەوەی. چەند هاوکێشەیەکی تیۆری پێشنیار کرا بۆ حیساب کردنی نەرمی وتوندی بۆ بنمێچە کونکریتی‌یە دوولایەکان لە ژێر هێزی بەشێوەیەکی رێك دابەش کراو بۆ گورینی بری گەرمی وبری شیش.ئامانجە تیۆری‌یەکان وپراکتیکەکان زۆرلەیك نزیك بوون ، وهاوکۆلکەی بەستن بۆ نەرمی وتوندی یەکان بون بە ٠،٩٤ و ٠،٩٥.

المطيلية والقساوة للبلاطات الخرسانية المسلحة المعرضة للحرارة العالية

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الخلاصة

تم دراسة المطيلية النسبية والقساوة للبلاطات الخرسانية المسلحة بعد تعرضها للدرجات الحرارية العالية وتبريدها. لقد تم صياغة معادلات تجريبية لحساب المطيلية النسبية والقساوة للبلاطات الخرسانية المسلحة بالاتجاهين تحت احمال موزعة بانتظام للمتغيرات (درجة الحرارة وكمية حديد التسليح) اعطت النتائج النظرية تقارباً جيداً عند مقارنتها مع النتائج العملية، وكان معامل الترابط للمطيلية والقساوة يساوي ٠،٩٤ و ٠،٩٥ على التوالي.

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وەرگیرا لە ١٠/٤/ ٢٠٠٠دا وەپەسەندکرا لە ١٧/٥/٢٠٠١دا.