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Flexural Behavior of Reinforced Concrete Partially Restrained Slab Specimens Subjected to Fire Flame

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جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل

كلية الهندسة

قسم الهندسة المدنية

سلوك الانحناء لنماذج البلاطات الخرسانية المقيدة جزءياً المعرضة للهب النار

رسالة مقدمة الى

كلية الهندسة في جامعة بابل

كجزء من متطلبات نيل درجة الماجستير

في علوم الهندسة المدنية

من علي ناصر حسين

اشراف

أ.م .د. مهدي صالح عيسى أ.م.د. غالب محسن حبيب

جمادى الاخره ١٤٢٨ **تموز ٢٠٠٧**

To

My Family

بسم الله الرحمـــــــن الرحـــــيم

With love and respect

وَأَنـزَلَ اللَّهُ عَلَيْـكَ الكِتَـابَ وَالْحِكْمَـةَ وَعَلَّمَـكَ مَـا لَـمْ تَكُـن تَعْلَمُ وَكَانَ فَضْلُ اللَّهِ عَلَيْكَ عَظِيماً *

صدق الله ألعلي العظيم

سورة النساء

الآية(١١٣)

Ali N. Hussein

CERTIFICATE

We certify that this thesis titled **“Flexural Behavior of Reinforced Concrete Partially Restrained Slab Specimens Subjected to Fire Flame ”** , was prepared by **“Ali Nassir Hussein”** under our supervision at Babylon University in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering.**

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الخلاصة

هذا البحث تم اجراؤه لدراسه سلوك الانحناء لنماذج سقوف خرسانيه مسلحه ومقيده جزئيا والتي تم تعريضها الى لهب النار المباشر ,وكذلك لدراسه تاثير لهب النار المباشر على خواص الخرسانه الاخرى.

خلال هذا البحث تم الاعتماد على دراسة سلوك ١٦ بلاطة خرسانيه مسلحة بابعاد مصغرة (٦٠٠× ٦٠٠ × ٤٠ مم) ومقيدة جزئيا من الجوانب الاربعة .خلطتان خرسانيتان بمقاومة انضغاط (٣٠ , ٣٨ ميگاباسكال) تم تصميمهما لتكونا الفئة (أ) و(ب) على التوالي .تم استخدام نسب حديد التسليح (٠.٠٠٥ , ٠.٠٠٩) لكل من الفئة (أ) و(ب) . تم انضاج النماذج في الماء لمدة ١٤ يوم ثم تركت في المختبر لتجف لمدة ١٤ يوم اخرى. في عمر ٢٨ يوم عرضت النماذج الى لهب النار .تم تعريض السطح الاسفل للنماذج الستة عشر الى درجاة الحرارة (٤٠٠ ,٥٠٠ ,٦٠٠ °س) لمدة تعرض تبلغ ساعة واحدة وبعد ٢٤ ساعه تم فحص النماذج بتسليط حمل منتظم لحين حصول الفشل .

تم فحص الامواج فوق الصوتية ومطرقة شميدت المرتدة للنماذج قبل وبعد التعرض الى النار.مع صب كل بلاطة تم صب مكعبات واسطوانات ومواشير لايجاد التغير في مقاومة الانضغاط ومعاير الكسر ومعامل المرونة نتيجة التعرض الى لهب النار. كذلك تم فحص التغير في قوة الخضوع والشد الحدي للحديد بسبب التعرض للنار.

وضحت النتائج تناقص قيم الحمل الاقصى بعد التعرض للنار حيث كان المتبقي من الحمل الاقصى بعد التعرض الى درجة الحرارة(٤٠٠ ,٥٠٠ °س) اكبر من الحمل الاقصى المتبقي بعد التعرض لدرجة الحرارة ٦٠٠ °م .نسبة المتبقي من الحمل الاقصى بدرجة ٦٠٠ °س كانت (٨٦ - ٨٧) و(٨٦ - ٨٥) لنسب حديد التسليح (٠.٠٠٥ , ٠.٠٠٩) للفئتين(أ) و(ب) على التوالي.

شهدت نتائج الفحوص اللا اتلافية بعد فحص نماذج البلاطات المعرضة للحرارة العالية نقصانا في القراءة مقارنة مع النماذج قبل التعرض .المتبقي من سرعة الموجات فوق الصوتية عند درجة حراره ٦٠٠ °س يتراوح بين (٥١ -٥٢ %) لنماذج السقوف للفئتين (أ) و(ب) على التوالي ولكن المتبقي من رقم الارتداد تراوح بين (٧٤ - ٧٥ %) في درجة حرارة ٦٠٠ °س لنماذج السقوف للفئتين (أ) و (ب) على التوالي .

مقاومة الانضغاط المتبقيه عند درجة حراره ٦٠٠°س تراوحت بين (٦٢ - ٦٣ %) لنماذج المكعبات للفئتين (أ) و(ب) ولكن المتبقي من معاير التصدع تراوح بين (٤٧ - ٥١ %) والمتبقي من معامل المرونه تراوح بين (٢٦ - ٢٩ %) في درجة الحراره ٦٠٠°س للنماذج للفئتين(أ) و(ب) على التوالي .

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Ali N. Hussein

Abstract

This study is conducted to investigate the flexural behavior of reinforced concrete partial restrained slab specimens subjected to direct fire flame and to study the effect of direct fire flame on the concrete properties.

During this research, the study of the behavior of slabs was based on sixteen reduced scale reinforced concrete slab specimens cast in (٦٠٠×٦٠٠×٤٠mm) (length× width× thickness respectively) and partialy restrained from four sides. Two concrete mixes with design compressive strengths of (٣٠ and ٣٨ MPa) designated as series A and series B respectively .Two steel ratios of (٠.٠٠٥, ٠.٠٠٩) were used. The specimens were cured for ١٤ days,and air dried in the laboratory for other ١٤ days , then at age of ٢٨ days they were subjected to fire flame. The specimens were exposed to fire temperature levels of (٤٠٠,٥٠٠ and ٦٠٠ °C) at the lower surface of slab specimens with exposure duration of one hour, then after ٢٤ hours; they were tested to failure under uniformly distributed load.

These slab specimens were tested for ultrasonic puls velocity and rebound number before and after exposure to fire. With each casting process of slab specimen (cubes ,cylinders and prisms) were casted to determine the change in compressive strength ,modulus of rupture and modulus of elasticity of concrete due to exposure to fire flame . The changes in yield and ultimate tensile strength of steel bars due to exposure to fire were also investigated .

It is clear from the results that the values of ultimate load capacity, decreased for all specimens after exposing to fire flame. The residual ultimate

load at temperature of (٤٠٠ and ٥٠٠°C) were higher than that at ٦٠٠°C for all specimens. At temperature around ٦٠٠°C and for steel ratio of (٠.٠٠٥, ٠.٠٠٩), the percentages of residual ultimate load ranged between (٨٦ , ٨٧٪) and (٨٦ , ٨٥٪) for series A and B respectively.

The non-destructive test results showed more reduction in the test results after exposure of slab specimens to fire compared with the control specimens.The residual ultrasonic puls velocity at ٦٠٠ °C ranges between (٥١ and ٥٢ %)for slab specimens of seriese (A) and (B) respectively .But the residual in rebound number was in the range of (٧٤ and ٧٥٪) at ٦٠٠ °C for slab specimens of series (A) and (B) respectively.the residual compressive strength at ٦٠٠ °C ranges between (٦٢ and ٦٣ %) for cube specimens of series (A) and (B) respectively.But the residual in modulus of rupture was in the range of (٤٧ and ٥١ %) and the residual modulus of elasticity ranged between (٢٩ and ٢٦٪) at ٦٠٠ ºC for specimens of series (A) and (B)respectively.

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Notations

Item	**Description**
(E $_c$)a	Modulus of elasticity of concrete after exposure to fire flame temperature(GPa)
(E $_c$)b	Modulus of elasticity of concrete before exposure to fire flame temperature(GPa)
E $_s$	Modulus of elasticity of the steel (GPa)
)a ´(fc	Compressive strength of concrete after exposure to fire (MPa)
)b ´(fc	Compressive strength of concrete before exposure to fire (MPa)
(fr)a	Flexural strength after exposure to fire (MPa)
(fr)b	Flexural strength before exposure to fire (MPa)
(RN)a	Rebound number test after exposure to fire
(RN)b	Rebound number test before exposure to fire
(U.P.V)b	Ultrasonic pulse velocity test before exposure to fire, km/sec
(U.P.V)a	Ultrasonic pulse velocity test after exposure to fire, km/sec

Chapter one

Introduction

١- ١ General

Concrete is widely used in building connstruction because all the content or basic material of it (except cement)are natural materials and available in enough amounts at low cost,and the process of bringing them to the location of the building is easy and simple .Concrete will obtain good stiffness and durability when it is reinforced with steel reinforcement.

The concrete building construction coud be exposed to the effect of fire . Human safety is one of the consideratuons in the design of residential ,public and industrial buildings.Unlike wood and plastics, concrete is incombustible and does not emit toxis fumes on expusure to fire .On the contrary of steel,when subjected to temperature between (٧٠٠-٨٠٠)ºC , concrete is able to retain an adequate strength for reasonably long periods, thus permitting rescue oprations by reducing the risk of structural collapse [١,٢,٣,٤].

There are many instances of exposing concrete structure members to elevated temperature .One of the most common instances of exposure is by accidental fire in buildings. Another instance of heat exposure may be found in some industrial equipments when concrete is used in places exposed to sustained elevated temperatures . Long exposure to elevated temperature is imposed on foundations for blast furnace and coke batteries, furnaces wall and dampers, industrial chimneys and flues, floors on which metal parts are heat –

treated , floors below boilers and kilns and nuclear- reactor pressure vessels[٥].When a reinforced concrete structure has been involved in afire , it is often possible to remain standing because of the good fire resisting properties of the concrete .This means that in dealing with such asituation , a choice can be made between reconstruction and reinstatement . Reinstatement can be often quicker and cheaper alternative. However,before a decision can be made , it is nessesary to establish whether or not the damaged structure is suitable for such treatment . To do this , its residual capacity for strutural performance must be assessed [٦]

The fire resistance of reinforced concrete slabs is expressed in terms of fire endurance as determined by standard fire tests.The fire endurance of the slab is then expressed as the time duration necessary to induce failure. The ASTM E-١١٩ standard method for floor slab fire tests specifies that a fire test will be considered as successful if :

١-The slab does not allow the passage of flames or gasses hot enough to ignite oven-dried cotton, and

٢-The rise in temperature of the unexposed surface is less than ١٢٠ °C(٢٥٠ °F) .For steel reinforcement , these standards specify that steel temperature should not exceed ٥٤٠ °C (١٠٠٠ °F)within the rated fire endurance [٧] .

In the structural design of buildings, in addition to the normal gravity and lateral loads, it is in many cases to design the structure to safely resist exposure to fire .However it is usually necessary to guard against structural collapse for agiven period of time [٨].

١- ٢ Research Objective

A lot of research on concrete subjected to high temperatures were carried out .The object of those investigations was to determine the strength and deformation properties of concrete at elevated temperatures and to find out the causes of the changes that the materials suffers in consequence of heat .The researchers exposed the concrete to higth temperatures in special furnaces.

There are indeed little research about specimens exposed to direct fire flame .

In the present work , there is an attempt to investigate the behavior of reinforced concrete partial restrained slabs after the exposure periods to fire flame.There are many variables considered in this investigation ,these cover the following aspects:-

١- The main parameter studied was the effect of fire temperature on flexural behavior of reinforced concrete partial restrained slabs.

٢- Studying the fire flame effect on the ultimate load carring cappacity of the reinforced concrete partial restrained slabs and comparing the results with control slabs.

٣-Studying the surface conditions and fire endurance of partial restrained concrete slabs.

٤- Studying the fire flame effect on mechanical properties of concrete, such as compressive strength, modulus of rupture and modulus of elasticity.

٥-Studying the fire flame effect on the specimens by using non-destructive tests, such as ultrasonic pulse velocity and Schmidt rebound hammer to estimate the degree of damage.

١- ٣ Research Layout

In this research there are five chapters:-

Chapter one provides a general introduction .

Chapter two present a review of both early and recent studied , including the effect of fire flame on the mechanical properties of concrete and reinforced concrete members (beams, frames and slabs) .

Chapter three deals with materials and experimental work,which include the program of testing .

Chapter four includes analysis of test results and their discussion.

Chapter five contains conclusions obtained from the test results and some recommendations for futher work.

Chapter Two

Literature Review

٢- ١ Introduction

Several factors control the response of concrete to high temperatures .Ingredients of concrete are important because both the cement paste and the aggregate consist of components that decompose through heating ,therefore that was very important to study the effect of fire on concrete [٩].

The behavior of reinforced concrete structures exposed to fire depends on the thermal properties of steel and concrete, strength and stiffness of the concrete and steel at elevated temperatures, and on the ability of structure to redistribute internal forces during the course of the fire [١٠] .

A number of research dealt with the effect of fire on concrete, steel reinforcement and reinforced concrete members. It is clearly stated that both concrete and steel are affected by exposure to fire.

Some of the investigations, which tended to evaluate the effect of exposure of concrete to high temperatures are discussed here.

٢-- ٢ Effect of Fire on Concrete

٢- ٢- ١ Effect of Fire on Normal Strength Concrete.

Abrams [١١] in (١٩٧١) investigated the effect of high temperature on the compressive strength of concrete by using (٧.٥ x١٥ cm) cylindrical specimens heated for short duration to temperature of (٩٣-٨٧١ °C) .The included variables were aggregate types (carbonate ,siliceous and lightweight).The test specimens were heated without load then tested hot, heated with load and tested hot ,and tested cool after heating .The original strength of concrete was (٢٣ -٤٥.٥ N/mm٢).He found that carbonate aggregate concrete and light weight aggregate concrete retained about ٧٥ % of their original strength at a temperature up to ٦٤٩ °C when heated with out load and tested hot .while the corresponding temperature for the siliceous aggregate concrete was about ٤٢٧ °C .He also found that the test procedure has a significant effect ,where the strength of the specimens stressed in compression during heating , was generally higher than the specimens that were not stressed during heating .Moreover, the unstressed residual strength (specimens heated ,cooled and tested) were lower than that the strength of the companion hot tested specimens.

Noriaki et al [١٢] in (١٩٧٢)**,** investigated the effect of temperature on the properties of concrete (compressive strength ,modulus of elasticity and

Poisson′s ratio). Cylinders (١٥٠ x٣٠٠ mm) were used .After ٢٨ days of curing the specimens were stored in sealed containers ,at (٤٠ , ٧٠ , ٩٠C) for a period of (١ – ١٣ Week), the test results showed that the compressive strength for sealed specimens decreased with rising temperature . They found the modulus of elasticity for sealed specimens at exposure to high temperature depends on the compressive strength . Poisson′ s ratio was not affected under the storage temperature but stayed in the range of (٠.١٥ -٠.٢٠).

Nasser and Marzuk [١٣] in (١٩٧٩) carried out an experimental study on the effect of high temperature on properties of mass concrete containing fly ash .Tests were made on (٧.٥ x٢٣.٥ cm)concrete cylinder by using ordinary Portland cement .A ٢٥ % replacement of cement by fly ash was used .After ٢٨ days of moist curing ,the specimens were transferred to an electric oven .The specimens ,were heated for ٦ months at five different temperature of (٧١,١٢١,١٤٩,١٧٥ and ١٣٢°C) .At each temperature minimum of three specimens were tested after being exposed for (٣,٧,١٤,٢٨,٥٦,٩١ and ١٨٠ days).All specimens were gradually cooled and tested at the room temperature .The test results showed that the strength and elasticity at(٧١ °C)were almost equal to those at(٢١.٤°C)at all exposed time .They found that the increase in the strength and modulus of elasticity after ٦ months of exposure at (٢١.٤ and ٧١°C)was about ٢٠٪ of those at ٢٨ days . They also noticed that at temperature range of (١٢١ to١٤٩ °C),the compressive strength was grater than that at (٢١.٤ °C).Furthermore ,they observed that after exposure to temperatures of(١٧٧ and ٢٣٢ °C)for ٦months the strength reduced to about ٥٣ and ٢٧٪ respectively while the modulus of elasticity was reduced to ٤٣ and ٢٥ % of the corresponding value. Finally they found that the deterioration of the structural properties at (١٧٧ and ٢٣٢ °C) was attributed to the transformation of most of tobermorite into crystalline alpha dicalcium silicates ,which has poor binding qualities.

Carette et al [١٤] in (١٩٨٢) published a research on the sustained high temperature effect on concrete made with normal Portland cement , normal Portland cement and slag, or normal Portland cement and fly ash. For each type of concrete ,compressive and splitting tensile strength were determined after ٢٨ days of moist curing ,before and after periods of temperature exposure ,also ,changes in weight ,pulse velocity and resonant frequency of the specimens were determined. For each condition of exposure ,small samples of mortar obtained from specimens broken in compression were examined ,the temperature range was from ٧٥ to ٦٠٠°C .Cylinders (١٠٢x ٢٠٣)were cast. After ٢٨ days of curing ,the specimens were stored in a normal room temperature for ١٦ weeks before heating . The exposure temperatures were ٧٥,١٥٠, ٣٠٠ ,٤٥٠ ,and ٦٠٠°C .The periods of exposure were ١ ,٤ ,and ٨ months .The test results showed that the compressive and splitting tensile strength decreased with the increase of temperature up to ٧٥°C . Their decrease was ١٠٪ with respect to the deference concrete strengths. At ١٥٠ ,٣٠٠ , ٤٥٠ and ٦٠٠°C the reduction in strengths was (١٠-٢٠ %), (٢٤ -٣٩ %) ,(٣٨ -٥٩ %) and (٥٠ -٧٥ %) respectively .They found that the in corporation of fly ash and slag in the concrete did not improve that mechanical properties of concrete after exposure to sustained high temperatures . This was true regardless of the exposure temperature and water –cement ratio. They also observed that the significant changes in the mechanical properties of the concrete under long –term exposure occurred within the first month.

Nuri [١٥] in (١٩٨٣) investigated the effect of high temperatures on some properties of concrete. The specimens were exposed to temperatures in the range of (٢٠-٦٠٠ °C) and the periods of exposure of heating were(٣٠,٦٠ and ٩٠ minutes)at different ages of concrete (٣,٧,٢٨,and ٦٠ days). Concrete cylinders (١٠٢*٢٠٣)mm were used for compressive and splitting tensile strengths.

He found that:

١. After ٣٠٠ °C exposure, concrete retained from (٥٩-١٠٢٪) and (٤٤ – ١٠٠٪) from original compressive and tensile strength respectively.
٢. After ٦٠٠ °C ,concrete retained (٢٨ – ٦٤٪) ,and (٢٠ –٦٢ %) from original compressive and splitting tensile strengths respectively .

Zoldner [٢] in (١٩٨٥)_stated that the quartz content in aggregate is the maine factor influencing thermal expansion of aggregate . A high quartz content to cause larger expansion due to heating .

During first heating , the cement past is subjected to two opposite effects. An ordinary thermal expansion based on kinetic molecular movements , and a hygrothermal volume change associated with the movement of internal moisture . Up to a temperature of ١٠٠ °C, the cement past expands, then it will contract at higher temperatures[١٦]. This contraction continues as a temperature rises as shown in Figure (٢-١)

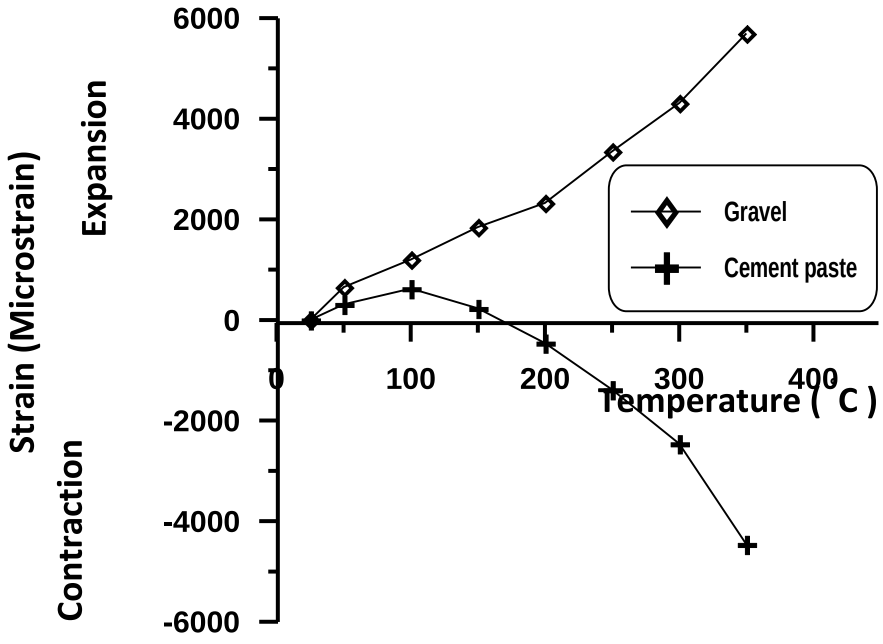


Figure (٢-١): Free thermal strain of cement paste and gravel [١٨]

Fahmi [١٧] in (١٩٨٦),investigated the influence of high temperature on the compressive strength and the tensile strength of concrete .The author found that the more decrease in the compressive strength and tensile strength happened during the first half hour from exposure time .He noticed that the decrease in tensile strength was more than the decrease in compressive strength .He also found that compressive strength increased in early age when it was heated to (١٠٠ C).

Elizzi et al [١٨] in (١٩٨٧), studied the effect of temperature on the compressive strength and density of concrete .They used (١٠٠ mm) cubes heated for a short duration (one hour) to temperature ranging from ٢٠ - ١٠٠ C and the ages of concrete at heating were (١٤ , ٢٨ , ٩٠ days) .The test results showed that the compressive strength decreased ١٠ % from the original strength up to ٤٠٠ C and at ٦٠٠ C the strength reduction was ٥٠ % from the original .They noticed that there was a large strength reduction when heated to temperature above ٤٠٠ C. They also mentioned that the small reduction in density up to ٣٠٠ C was a result to the loss of the free water from concrete specimens .At temperature above ٣٠٠ C ,large reduction in density took place because of loss of the water in concrete.

Kumar et al . [١٩] in (١٩٨٩)studied the effect of temperature of the properties of super plasticized concrete such as compressive strength,modulus of elasticity and poisson's ratio .The test specimens were (١٥٠mm)cubes and (١٠٠x١٠٠x ٥٠٠ mm) prisms .The specimens were exposed to temperatures of ١٥٠, ٣٠٠ ,٤٥٠ and ٦٠٠°C for ٣ and ٦ hours in an electrical furnace .The test results showed that the residual strength of super plasticized concrete increased at ٣٠٠ °C while conventional concrete decreased .At ٤٥٠ °C the residual strength in super plasticized concrete decreased more than conventional concrete . They also noticed a slight increase in compressive strength for both concrete below ٣٠٠°C while there was a rapid drop beyond ٣٠٠°C .They found that the modulus of rupture decreased as the temperature increased , but the reduction in super plasticized was more than in conventional concrete .They also observed that the super plasticized concrete possessed better fire resistance than the conventional concrete.

Valiasis and Papayianni [٢٠] in (١٩٩٠) studied the effect of high temperature on the mechanical properties of concrete in which Portland cement concrete cylinder specimens (١٥٠ x٣٠٠ mm)were used. after ٢٨ days of curing and six months of draying , the specimens were exposed to four temperature levels ,٢٠٠ ,٤٠٠ ,٦٠٠ and ٨٠٠ °C without any imposed load .Groups of three specimens each were crushed at ١ day ,٧ days and ٣ months after heating .The included variables were compressive strength ,splitting tensile strength and modulus of elasticity .The test result showed that the concrete with Portland cement only had a reduction in strength about ٢٥ % .While the concrete pozzolanic material showed a reduction from ٣٨ % to ٥٠ % at ٢٠٠°C . They observed that at a temperature over ٤٠٠ °C all tested concrete suffered deterioration and lost ٧٠ – ٨٠ % of their initial strength.also , they found that the thermal behavior of concrete with lignite fly ash in closer to those of concrete with Portland cement of Greek –type.

Umran[٢١] in (٢٠٠٢) studied the effect of fire flame on some mechanical properties of concrete .Two concrete mixes (١:١.٦:٣.٢) with (w/c) (٠.٥٢) and (١:١.٢:٢.٧) with w/c (٠.٤٥) were used with compressive strength ranged from (٣٠ and ٤٠ MPa) .The properties investigated were density , compressive strength , splitting tensile strength , flexural strength and modulus of elasticity .Two non-destructive tests, the ultrasonic pulse velocity and rebound hammer were used. The specimens were subjected to fire flame temperatures ranging from (٤٠٠-٧٠٠ °C) at different ages of ٣٠ , ٦٠ and ٩٠ days .Three temperature levels of ٤٠٠ °C, ٥٠٠ ° C and ٧٠٠ °C were chosen with four different exposure duration of ٠.٥,١.٠,١.٥ and ٢.٠ hours.

He found that:

١. The properties of concrete were very sensitive to fire flame and they deteriorated , when the fire flame intensity increased for all ages and periods of exposure .

٢. The residual compressive strength ranged between (٧٠ -٨٥٪) at ٤٠٠ °C ,(٥٩ -٧٨ %) at ٥٠٠ °C and (٤٣ -٦٢ %) at ٧٠٠ °C. Cooling by water caused further reduction in the compressive strength , compared with specimens cooled in air , the percentage reduction in compressive strength of the specimens cooled in water was (٢-٨٪) more than the specimens cooled in air .

٣. The residual tensile strength was (٦٧ -٧٨٪) at ٤٠٠°C, (٤٠ -٦٧٪) at ٥٠٠ °C and (٢٠ ٤٥٪) at ٧٠٠ ° C. But the reduction in splitting tensile strength for specimens cooled in water showed more reduction than specimens cooled in air by (٣-١٤٪).

٤. The residual flexural strength was in the range of (٧١ -٧٩٪), (٤٢ -٥٨٪) and (٢٢-٤١٪) for ٤٠٠ °C,٥٠٠ °C and ٧٠٠ ° C fire flame temperature.

٥. The residual modulus of elasticity ranged between (٥٥- ٧٥٪), (٣٤-٥١٪) and (١٦-٣٤٪) for ٤٠٠°C,٥٠٠°C, and٧٠٠ °C fire flame temperature, respectively.

Al-Owaisy[٢٢] in (٢٠٠٤) , studied the effect of evaluated temperatures on bond between reinforcing steel bars and surrounding concrete ,and compressive strength of concrete .Cube specimens (١٠٠ mm) were used to test the compressive strength with mix proportion of (١ :١.٥ :٣) . Three groups (A , B and C)were used .Group (A)had water cement ratio (٠.٤)and compressive strength (٤٣ Mpa) while group (B) and (C) had water cement ratio of (٠.٥) and (٠.٦) respectively with compressive strength (٣٦ Mpa)and (٣٠ Mpa) respectively .The specimens were subjected to (١٥٠ . ٣٥٠ , ٥٠٠ and ٧٠٠ °C) for one hour .The author noticed that the percentage residual concrete compressive strength for water cement ratio of (٠.٤ , ٠.٥ and ٠.٦)were about (٨٧ ,٧٨ and ٧٦ %) respectively at (١٥٠ °C), (٩٤ , ٨٨ and ٨١ %) respectively at (٣٥٠ °C) , and (٦١ , ٦٤ and ٥٣ %) respectively at (٥٠٠ °C) . At (٧٠٠ °C) the three groups of specimens retained about (٣٦ %) only of their compressive strength .

٢- ٢- ٢ Effect of Fire on High Strength Concrete.

Carlos and A . J . Durrani [٢٣] in (١٩٩٠) **,** investigated the effect of transient high temperature on strength and load – deformation of high strength concrete. The concrete strength varied between (٣١.١ MPa) to (٨٩ MPa) and the temperature exposure was in range of (٢٣ °C) to (٨٠٠ °C) .

Three types of tests are commonly used to study the effect of transient high temperature on the stress- strain properties of concrete under axial compression :-

١- Unstressed tests where the specimens are heated under no initial stress and loaded to failure at the desired elevated temperature .

٢- Stressed tests where a fraction of the ultimate compressive strength at room temperature was applied and sustained during heating and, when the target temperature was reached ,the specimens were loaded to failure .

٣- Residual unstressed tests where the specimens were heated without any load ,cooled down to room temperature ,and then loaded to failure.

The authors found the following conclusions :-

١-When exposure to temperature in the range of ١٠٠ to ٣٠٠ C ,high strength concrete showed a ١٥ to ٢٠ percent loss of compressive strength .As the strength of concrete increased , the loss of strength from exposure to high temperature also increased.

٢- After an initial loss of strength ,the high –strength concrete recovered its strength between ٣٠٠ and ٤٠٠ C ,reaching a maximum value of ٨ to ١٣ percent above the room temperature strength .

٣- At temperatures above ٤٠٠ C ,the high –strength concrete progressively lost its compressive strength which dropped to about ٣٠ percent of the room temperature strength at ٨٠٠ C .

٤ – The modulus of elasticity of the high –strength concrete decreased by ٥ to ١٥ percent when exposed to temperature in the range of ١٠٠ .

Chan and Sun [٢٤] in (٢٠٠٠) carried out an experimental program to study the mechanical properties and pore structure of high performance concrete (HPC)and normal – strength concrete after exposure to high temperature . after the concrete specimens were subjected to temperature of ٨٠٠ °C, their residual compressive strength was measured .The porosity and pore size distribution of the concrete were investigated by using mercury intrusion porosimetry .The test result showed that (HPC) had higher residual strength , although the strength of (HPC) degenerated more sharply than the normal – strength concrete after exposure to high temperature .They found that the changes in pore structure could be used to indicate the degradation of mechanical property of (HPC) subjected to high temperature .Another paper published by the same authors[٢٥] in (٢٠٠٠) investigated the effect of heated and cooling regimes on residual strength and micro structure of normal strength and high performance concrete after they were exposed to high temperatures ,٨٠٠ ,١١٠٠°C and two cooling regimes .The test results obtained showed that the residual strength of both (HPC)and (NSC) dropped sharply after exposure to high temperatures .They observed that water cooling which resulted in a significant thermal shock , caused a bit more severed deterioration in strength compared to furnace cooling .They found that the thermal shock was not necessarily the primary cause for spalling in (HPC).They used mercury intrusion porosimetery to measure variation in the pore structure of concrete .They also noticed the significant changes in the cumulative pore volume curves before and after high temperatures in both (NSC)and (HPC). Moreover ,they found that the cumulative pore volume of (HPC) increased more remarkably than of (NSC).

Habeeb[٢٦] in (٢٠٠٠**) ,** studied the effect of high temperatures on some mechanical properties of high strength concrete (HSC) such as compressive strength, flexural strength and dynamic modulus of elasticity (Ed). Three design strengths were investigated ٤٠, ٦٠ and ٨٠ MPa.. The specimens were heated slowly to five temperature levels (١٠٠, ٣٠٠, ٥٠٠, ٦٠٠ and ٨٠٠ ˚C), and to three exposure periods ١, ٢ and ٤ hours .

He found that :

١- (HSC) is more sensitive to high temperatures than (NSC).The residual compressive strength ranged between (٩٠ – ١٠٦٪) at ١٠٠̊C, (٧٢-١٠٣٪) at ٣٠٠ °C, (٥٥ – ٨٧٪) at ٥٠٠ ˚C and (٢٢-٦٦٪) between (٦٠٠-٨٠٠ ˚C).

٢- The flexural strength was found to be more sensitive to high temperature exposure than compressive strength, the residual flexural strength was in the range of (٩٢ – ٩٨٪), (٥٢-٩٨٪) and (٢٩- ٤٧٪) at ١٠٠̊ C, ٣٠٠̊ C and ٥٠٠ ̊C respectively and (٢-٣٠٪) at ٦٠٠ –٨٠٠ ˚C .

٢-٣ Effect of Fire on Steel Reinforcement.

Edward, and Gamble[٢٧] in (١٩٨٦) submitted a study about effect of high temperature on yield stress and tensile strength on reinforcing deformed bar (ASTM-A ٦١٥ grade ٦٠) . Steel bars were exposed to fire of (٥٠٠ – ٨٠٠ °C).

The authors found :

١- Modulus of elasticity did no effect at elevated temperature

٢- At temperature ٧٥٠ °C ,the reduction in yield stress was ٢٧ %of original strength .

٣- The reduction in tensile strength was ١٧ %of the original strength at temperature ٧٠٠ °C.

Moosa [٢٨] in (٢٠٠٠) , investigated how to protect the steel elements in concrete subjected to fire . He said that when the temperature increases to (٥٣٨ C) half of yield strength of steel was lost. The author suggested procedures to protect the steel elements when it is subjected to fire by spraying by in alienator cement materials or by it elastic pasts.

٢- ٤ Effect of Fire on Reinforced Concrete.

Hannant and Pell [٢٩] in (١٩٦٢) ,investigated the thermal stresses in reinforced concrete slabs. An experimental and theoretical investigation into the stresses induced in steel and concrete in reinforced concrete slabs subjected to high temperatures and thermal gradient was done. They found that the observed stresses in the steel are dependent on time and previous temperature cycling of the slab. Initially, the stresses in the steel were in close agreement with the values derived from the elastic analysis, but as shrinkage and creep increased, with time and temperatures, large losses of tensile stress were measured until, in several cases, the steel developed compression even while the thermal gradients were considerable. The main cause of loss of tensile stress in the steel was attributed to the increased to the increased rate of concrete shrinkage at temperatures near or above ١٠٠ ºC, with secondary effects due to creep and reduction in the expansion coefficient.

Garlson ,Selvaggio [٣٠] in (١٩٦٤), investigated the effect of aggregate type and loading on the strength of prestress (**I**) beam section of length (٦١٠٠ mm). The study included :

١- Aggregate type :-The used gravel were ,natural sand , silica aggregate ,crushed stone from dolomite type in addition to three types of light weight aggregate type (expanded shale) .

٢- Load intensity :- Applied loads on beams has been distributed in five points spaced at the same distance ,then it subjected to standard ignition according to American specification (ASTM-E١١٩) and the test has continued until rupture , and they concluded that :-

١- Aggregate has great effect on strength duration of pretensioned beams for standard ignition ,that the duration of light weight aggregate longer than that of silica aggregate ,because light weight aggregate has little thermal conductivity with respect to the silica aggregate .
٢- Behavior of beams which included natural aggregate was similar to the behavior of beams which included crushed stone .
٣- The end restraint of the beams conducted to increase the period of resistance to fire about (٢٢٪) compared with simply supported beams .
٤- The end restraint force in normal concrete was more than in light weight concrete .

Gostaffero and Abrams [٣١] in (١٩٦٩) **,**investigated the strength of slabs and floors which consist of two layers (two –course floors and roofs)for standard ignition , then standard slabs from reinforced concrete with top layer or covered with lower layer , for the best methods and material to extend the duration of loading of roofs and slabs to ignition. The type of failure depends on the thermal translation according to ASTM –E١١٩ specification , which says that the maximum period of resistance to the fire for roofs happens when the temperature of unexposed surface arrives to (١٣٩ C).the specimen dimensions were (٩٠٠x٩٠٠ mm). and the study included ,

١- Using different alienator materials with different thickness to flatten the upper surface of roofs such as (perlite concrete, cellular concrete and vermiculite concrete).
٢- Using different alienator materials with different thickness to flatten the lower surface of roofs such as (sprayed mineral fiber, vermiculate type MK and in tumescent mast).
٣- Roofs thickness was from (٣٧ mm) to(٦٤ mm).
٤- Using three types of aggregate carbonation aggregate ,silicon aggregate and light weight aggregate.

The authors noticed the following conclusion :-

١- the roofs made from silica aggregate give more resistance to fire from roofs which made from carbonate aggregate .
٢- they found relation ship between resistance period ,thickness of floors , thickness of alienator layer and alienator layer type for different thickness of floors.

Abrams and his group [٣٢] in (١٩٧٠) , investigated the effect of fire on concrete joist floors and roofs .included exposure of eight floors and roofs to the standard fire .The specimen dimensions were (٥٥٠٠ x٤٣٠٠ mm) while the girder dimension in longitudinal direction was (١٣٠ mm)in width and (٢٥٠ mm)in depth .Data has been recorded at surface without subjection to temperature that they include deviation and extension and thermal thrust , the temperature of that surface and reinforcing steel during test ,slab had been permitted to extend (٨-٢٨) mm in longitudinal direction then the extension had restrained (in less amount in transverse direction), loading has been distributed at (١٦) point on slab surface .

The authors obtained the following conclusions :-

١- Most expansion in all specimens happened in the first forty minutes from exposure to standard fire.

٢- Micro cracking appeared in the lower surface after exposure to fire . When the humidity was decreased, the width of cracks was increase.

٣- The covered roofs by alienator materials were not affected in temperature ,and alienator materials did not fail .

٤- Regular formulas were used to find the strength of specimens .

Ellingwood and shaver [٣٣] in (١٩٧٧)investigated the effect of some factors such as the temperature and yield stress of reinforcing steel and the average degrease in resistance of reinforcing steel and the concrete cover of reinforced concrete on the behavior of simply supported beam exposed to stander fire . The analysis method includes finding the coefficients of the amount of suspect in the yield stress , available information accuracy about temperature and yield stress and the depth of the reinforcing bar and the reduction in yield stress to the original stress , which affect the amount of the maximum strength of the section .Relations of suspect coefficient of these variances were derived . By using these coefficients, the maximum resistance of the section at any temperature degree could be assessed . A relation was also derived to count the beam resistance period of fire . They have concluded the followings :

١- The beam resistance to fire increased when the thickness of the concrete cover of the reinforced concrete beam increased because the bar temperature keeps low .

٢- The coincidence between the theoretical calculations and practical results when compared was acceptable .

٣- The main factors , which affect determining the beam behavior ,are the accuracy of assessing the bar temperature and the changes of its properties by heat.

Fahmi and Khalil [٣٤] in (١٩٩٢) studied the effect of high temperature exposure on the behavior of prestressed concrete beams .The specimens used were unbounded post – tentioed beams having the dimension of (٨٠x١٢٠x٩٠٠)mm . They were heated to a temperature ranging between ٢٥ – ٨٠٠ °C and ate age of ٢٨ and ٩٠ days to the specified temperatures for periods ١ , ٣ and ٥ hours . The beams were reinforced with ١٠mm diameter prestressed deformed bars and ٣ mm and ٤ mm bars for longitudinal and stirrups respectively .Cylindrical concrete specimens with dimension (١٥٠ x٣٠٠) were used for compressive strength and modulus of elasticity . Prisms of (١٠٠x١٠٠x٤٠٠) were used for flexural strength .The test results showed that there is a slight increase in compressive strength at temperatire up to ٣٠٠ °C at ٢٨ days age . At ٦٠٠ °C and ٨٠٠ °C the compressive strength reduction was ٥٢ %and ٨٢ % in comparison with original strength respectively .They also found that the flexural capacity of all prestressed concrete beams had decreased with the increase of the temperature . They noticed that the reduction in modulus of elasticity and flexural strength at ٨٠٠ °C exposure were ٩٧ % and ٩١ % from the original values respectively .

Sanjayan and Stockes [٣٥] in (١٩٩٣) carried out an investigation to study spalling of concrete in fire . They observed that the high strength concrete might be more prone to spalling in the fire than the normal strength concrete . Moreover , they noiticed that the reason for spalling could not be attributed entirely to the large cover because a similar cover at web did not cause any spalling .No spalling occurred in the web ,possibly because in the web concrete was exposed to three sides and therefore the distance for the moisture to escape was much shorter and also because of the existence of wider flexural cracks in the web .

Hidayat [٣٦] in (١٩٩٤), investigated the experimental and theoretical investigation concerning the behavior of reinforced concrete slabs subjected to high temperatures. The experimental part included fabricating and testing ١٨ reinforced concrete slab specimens having dimensions of (٦٠٠ × ٦٠٠ × ٤٠mm), with different steel ratios.The concrete specimens were heated in electrical furnace for one-hour period of exposure at four temperature levels (٣٠٠,٤٠٠,٥٠٠,٦٠٠ and ٧٠٠°C) . The author concluded that the percentage of residual ultimate load was ٦٠ %,٨٠٪ ,٩١٪ , ٩٥٪ and ٩٧٪ at temperature of (٧٠٠, ٦٠٠, ٥٠٠ , ٤٠٠ and ٣٠٠°C)

Kadhum [٣٧] in (٢٠٠٣) ,investigated the cracking behavior due to the restrained drying shrinkage of the reinforced concrete slabs then subjected to direct fire flame .These slabs were externally restrained by different end restraints. Cracking was detected when these slabs were subjected to fire flames and shrinkage after burning. Reduced scale slab models were used .Slab movements, crack spacing, crack width and crack lengths were measured before and after exposure to fire flame.

The reinforced concrete slabs were exposed to drying shrinkage for a period of two months. Then, they were exposed to direct fire flame temperature of ٦٠٠°C for ١.٥ hour period of exposure at the same day, without any imposed loads during burning. Then, the slabs were cooled to the laboratory temperature .A comparison of the slabs behavior before and after exposure to fire flames was made. From the results obtained before and after burning, it was observed that there was a variation in the crack width along the slab length. The author concluded that the maximum cracks width before burning was(٠.٢٤,٠.٢٥٥ and ٠.٢٧٥mm) for two, three and four end-restrained slabs respectively. The maximum cracks width for free, two end, three end and four end restrained slabs during and after burning was (٠.٢٥, ٠.٧٥, ٠.٧٢٥ and ٠.٧١mm) and (٠.٠٧, ٠.٦٧٥, ٠.٧ and ٠.٧٥mm) respectively. He noticed that the maximum deflection recorded was during burning (١.٩٨mm) for free slab, whereas the minimum deflection during burning recorded was (٠.٨٥mm) for four end restrained slab. After period of ٦٠ days from burning the maximum and minimum deflections were (٠.٦٥ and ٠.٦)mm respectively .Therefore , it is obvious from the test results that the mid –span deflection of free end slab was greater by ٥٧ %than that of the four end restrained slab .

Smantha J and all [٣٨] in (٢٠٠٤) , investigate the influence of thermal curvature on the failure mechanisms of rectangular slabs. Two sizes of slabs were tested, whose nominal dimension (in mm) were ٩٢٠x٦٢٠x١٥ and٩٢٠x٦٢٠x٢٢, with the supported area being ٨٥٠x٥٥٠. The four corners of the slab were loosely clamped to restrain vertical upward movement, but no horizontal restraint was provided at the supported edges. The heating device was constructed from a steel box lined with insulation board to increase the heating rate and protect the steel casing. Heating was generated by four electrical elements within the steel box.

The slabs showed similar rates of deflections between ٢٠°C-١٥٠°C. The slabs of depth ٢٢mm deflection were lower than for the ١٥mm thick slabs. The rate of deflection for the slab reinforced with smooth wire were less than for the equivalent slab using deformed wire.

Karim [٣٩] in (٢٠٠٥), investigated the effect of fire flame on the behavior of reinforced concrete slab specimens during and after exposure to fire. The experimental work included casting and testing twenty four reinforced concrete slab specimens with dimensions of (٦٠٠×٦٠٠×٤٠mm) divided into two series with target compressive strength of (٣٠ and ٣٨ MPa) designated as series A and B respectively .Each series was reinforced with two steel ratios of (٠.٠٠٤٩٢ and ٠.٠٠٨٧٥) .

Sixteen reinforced concrete slab specimens were subjected to fire flame at the lower surface only to reach temperatures around of (٤٠٠,٥٠٠ and ٦٠٠ °C) for one hour, then they were cooled gradually to room temperature. After that, they were tested in flexure to failure under uniformly distributed load .

Based on the results of this work, it can be concluded that the ultimate load capacity of the reinforced slab specimens decreased with the increase in fire temperatures. The higher decrease occurred in the slab specimens having higher steel ratio and subjected to ٦٠٠ °C .The residual load capacity of reinforced slab specimens at ٦٠٠ °C ranges between (٨٤.٢- ٨٦٪) for slab specimens of series (A) which were reinforced with steel ratios of (٠.٠٠٨٧٥,٠.٠٠٤٩٢) respectively and (٨٣.٧-٨٥٪) for slab specimens of series (B) with the same steel ratios. The fired slab specimens were found to be capable of resisting the service load but with a decreasing factor of safety.

Eight reinforced slab specimens were uniformly loaded to two levels of loading and exposed to fire flame. The first level was ٤٠٪ of the ultimate load of the reinforced slab specimens (٢٢,٣٢,٢٣.٢,٣٣.٦ kN) and the other was the calculated service load (٣٤.١,٤٧.٥,٣٥.٥,٤٨.٨ kN) . The deflections of these slab specimens were measured .With respect to the increment in deflection of these slab specimens ; the fire resistance durations were found to be (١٢٦,١١٧,١١٧ and ١٠٥ minutes) for slab specimens which were loaded with ٤٠٪ of the ultimate load and (١١٠,٩٦,١٠٠ and ٩٠ minutes)for slab specimens which were loaded with service load .

٢-٥ Effect of Fire on Non-Destructive Tests

٢-٥-١ Rebound Method.

The surface hardness tests are simple to use and provide a large number of readings in a short time . The surface hardness of concrete is tested by the

"Schmidt Rebound hammer". This test estimates the surface hardness by the rebound number, which can be taken as a measure of the concrete strength and percentage of voids [٤٠,٤١] .

٢- ٥- ٢ ***Ultrasonic Pulse Velocity (U.P.V).***

The ultrasonic pulse velocity test has been used for testing concrete both in laboratory and in the field [٤٢] . The ultrasonic test is a useful tool for assessing the uniformity of concrete and detecting cracks, voids, or honeycombing. It gives useful information about the size of micro – cracked zone and crack growth and the interior structure of the concrete element [٤٣,٤٤,٤٥].

Changes in properties occur in concrete as a result of exposure to high temperatures such as in the case of fire. The measurements of pulse velocity are usually indicative of changes in strength; this method has high potential for assessing fire damage [٤٦].

A considerable number of research works had dealt with the effect of elevated temperature on the non –destructive tests of concrete.

Logothetis and Economou[٤٧] in (١٩٨١) studied the effect of high temperatures on the properties of concrete using non-destructive methods such as the rebound hammer and pulse velocity. Concrete cubes (٢٠٠) mm were tested .The specimens are consisted of ٣٢ specimens subjected to different curing conditions .The temperatures (٤٠٠,٥٥٠ and ٨٠٠ °C) were used with three periods of exposure (١, ٢ and ٣ hours).

They found that:

١. The reduction in pulse velocity was (٢٨-٣٠٪)(٤٣-٤٧٪) and (٥١-٥٩٪) at (٤٠٠,٥٥٠ and ٨٠٠°C) respectively ,for all period.

٢. The decrease of in Rebound number was about (١٣-١٩٪),(١٥-٢٠٪) and (٢٠-٢٨٪) at(٤٠٠,٥٥٠ and ٨٠٠°C) respectively, for all period.

Mahmoud [٤٨] in (١٩٩٥) published a research on the strength of prestressed concrete girder of a hall roofs exposed to three hour fires . The roof consisted of a gird of prestressed secondary girders forming a dome like roof . This dome was supported on four peripheral main prestressed concrete large girders ,he made visual inspection and concrete testing .The concrete tests were ultrasonic pulse velocity (UPV) and core test .Frome the colours of concrete surface , spalling at various locations and conditions of debris on the floor , he concluded that the temperature inside the hall reached about ٦٠٠ °C .From ultrasonic pulse velocity and core test , he found that the concrete compressive strength was equivalent to ٢٧.٥ MPa . While the original strength from project document was about ٤٩.٦ MPa .He also found that the ratio of concrete strength after and before fire was ٠.٥٦.

Essa.M.S. [٤٩] in (١٩٩٩) studied the effect of fire flame on compressive strength of concrete by ultrasonic pulse velocity test and Schmidt Rebound_hammer test. Two groups of concrete specimens were used . Group A with w/c ratio of ٠.٥ and mix proportion (١ :٢:٤) and group B with w/c ratio of ٠.٥٥ and mix proportion (١ :١.٥:٣) .

He found that:

١. At (٥٠٠ °C) ,the fire flame leads to reduce the ultrasonic pulse velocity by about (١٦- ٣٢٪) and (٣٩-٥٦٪) for fire durations of period (١ and ٢ hrs) respectively.

٢. At (٨٠٠ °C) , the ultrasonic pulse velocity decreases by about (٥٠٪).

٣. Burning causes to decrease Rebound number by about (١١-١٢٪) and (١٦-٢١٪) for (١ and ٢ hrs)burning durations respectively.

٢- ٦ Temperature –Associated with Fire.

The values of temperature associated with fires are according to the ASTM-E١١٩ [٧] standard curve which can be described approximately by the following expression:

If t < ٧٢٠٠ sec.

Tf =*To* + ١/١.٨ [١٠٤٤ + tanh (٠.٠٠٠٢٣٤١٣t) – ٤٩٨.٢ tanh (٠.٠٠٠٢٧٠٤٤t)

+ ١٢٨٦ **tanh (٠.٠٠٢٤٧٥t)].**

Where; t: - time in seconds.

Tf: - the fire temperature at t (°C).

To: - initial temperature (°C).

The curve representing this function; known as the “standard time – temperature curve”, [٧]

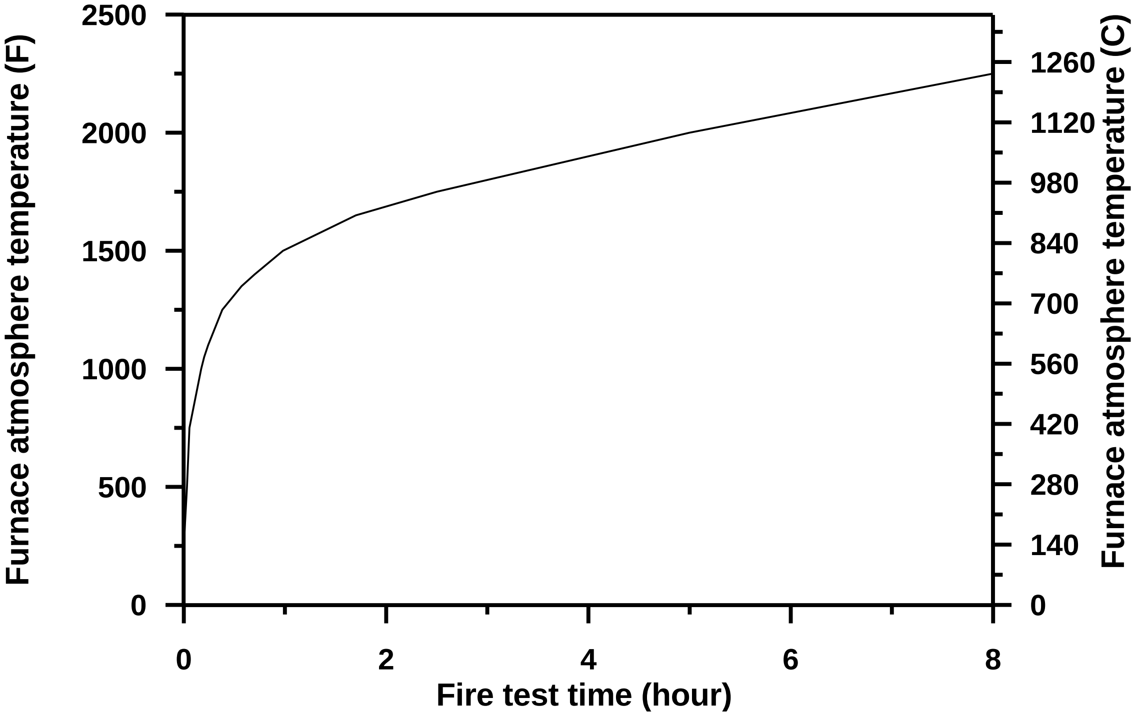


Figure (٢-٢):-Standard time-temperature relationship of furnace atmosphere (ASTM E ١١٩)[٧]

Chapter Three

Experimental Work

٣- ١ General.

In this chpter, the detail of experimental program of the present work is presented .Includes detail the materials used , specimens preparation and tests procedure . Two concrete mixes with design compressive strengths of (٣٠ and ٣٨ MPa) designated as series A and series B respectively .Two steel ratios of (٠.٠٠٥, ٠.٠٠٩) were used.Experimantel variables were :

١- Fexural characteristics of reinforced concrete restrained slab specimens .

٢- Compressive strength .

٣- Modulus of rapture .

٤- Modulus of elasticity.

The study of the behavior of slabs was based on sixteen reduced scale reinforced concrete slab specimens caste in (٦٠٠×٦٠٠×٤٠mm) (length× width× thickness respectively). The specimens were cast, water cured for ١٤ days,and air dried in the laboratory for ١٤ days .The spesimens were put inside the steel restraining frame three days before test date ,this method of restrained was adopted by other recearcher [(٥٠)] also, then at age of ٢٨ days they were subjected to fire flame. Sixteen slab specimens were exposed to fire temperature levels of (٤٠٠,٥٠٠ and ٦٠٠ °C) at the lower surface of slab specimens with exposure duration of one hour, then after ٢٤ hours; they were tested to failure under uniformly distributed load.

٣- ٢ Materials

٣- ٢-l Cement

The cement used in this study is ordinary Portland cement (OPC) produced by **Ras Al -Khaima** cement factory . Tables (٣-١) and (٣-٢) , show the chemical analysis and the physical properties respectively, of the cement used in this study . Testing of cement was conducted in the laboratories of the Consultant Engineering Bureau in Babylon University. The compliance of the cement is done according to the Iraqi standard No.٥. (IQS ٥:١٩٨٤) [٥١] for the chemical analysis and for the physical properties specified in this standard .

Table (٣-١): Physical properties of the cement used

Physical properties	**Test results**	**I.Q.S.٥:١٩٨٤[٥١] limits**
Fineness ,Blaine,cm^{٢}/gm	٢٥١٠	≥٢٣٠٠
Setting time ,Vicat's method		
Initial hrs: min	١: ٧٥	≥ ٠٠ : ٤٥
Final hrs : min	٤: ٠٥	≤ ١٠ : ٠٠
Compressive strength of ٧٠.٠ mm cube , MPa		
٣ days	١٩	≥ ١٥
٧ days	٢٨.١	≥٢٣

Table (٣-٢) : Chemical composition of the cement

Oxide	**(%)**	**I.Q.S.٥:١٩٨٤**[٥١] **limits**
CaO	٦٣.٩٠	………
$SiO_{٢}$	٢٠.٢٦	……...
$Fe_{٢}O_{٣}$	٣.٣٢	………
$Al_{٢}O_{٣}$	٤.٨٢	………
MgO	١.٢١	≤ ٥.٠
$SO_{٣}$	٢.٤٤	≤ ٢.٨
Free Lime	١.٢٠	-
L.O.I	٣.٥٥	≤ ٤.٠
I.R	-	≤ ١.٥
Compound composition	**(%)**	**I.Q.S.٥:١٩٨٤ limits**
$C_{٣}S$	٥٧.١٩	………..
$C_{٢}S$	١٤.٩٤	………..
$C_{٣}A$	٤.١٦	……….
$C_{٤}AF$	١٠.١٠	……….
L.S.F	٠.٩٤	٠.٦٦-١.٠٢

٣- ٢- ٢ *Fine Aggregate*

Natural sand from **AL-Akaidur** region was used. The results of physical and chemical properties of the sand are listed in Table (٣-٣). Its grading conformed to the IQS (No.٤٥:١٩٨٤)(٥٢) .

Table (٣-٣) : Properties of fine aggregate

Sieve size (mm)	**Percent passing**	**I.Q.S.٥:١٩٨٤(٥٢) limits**
١٠.٠٠	١٠٠	١٠٠
٥.٠٠	٩٦	٩٠-١٠٠
٢.٣٦	٨٥	٨٥-١٠٠
١.١٨	٧٨	٧٥-١٠٠
٠.٦٠	٦٠	٦٠-٧٩
٠.٣٠	٣٠	١٢-٤٠
٠.١٥	٤	٠-١٠
pan	٠	٠
Properties	**Test results**	**I.Q.S.٥:١٩٨٤(٥٢) limits**
Sulphate content SO_3%	٠.٤١	≤٠.٥
clay	٢.٢	≤٣.٠
Specific gravity	٢.٦٥	
Absorption	١.٤	

٣- ٢- ٣ *Coarse Aggregate.*

The gravel used was brought Al-Nibaii area with a maximum size of ٢٠ mm. The gravel was washed, and then stored in air to dry. The gravel used conforms to the Iraqi specification No.٤٥/١٩٨٤. The grading and other properties of this type of aggregate were tested and shown in Table(٣-٤).

Table (٣-٤) : Properties of coarse aggregate

Sieve size (mm)	Percent Passing	I.Q.S.٥:١٩٨٤(٥٢) limits
٤٠ ٢٠ ١٠ ٥ pan	١٠٠ ٩٨.٨ ٥١ ٩ ٠	١٠٠ ٩٥-١٠٠ ٣٠-٦٠ ٠-١٠ ٠
Properties	**Test results**	**I.Q.S.٥:١٩٨٤(٥٢) limits**
Sulphate content , $SO_٣$%	٠.٠٨	≤ ٠.١
Specific gravity	٢.٦٤	-
Bulk density kg/$m^٣$	١٦٩٤	-
Absorption (%)	٠.٧	-

٣- ٢- ٤ Water

Tap water was used throughout this work for both mixing and curing of concrete.

٣- ٢- ٥ Reinforcing Steel.

Plain steel bar ٤mm in diameter were used as reinforcement to test slab specimens. The yield tensile stress of the steel is ٣٤٢ MPa.

٣- ٣ Mix Proportions

٣- ٣- ١ Mix Design

The concrete mix was designed according to (ACI-٢١١.١-٩١).This mix was design to give the target design strength of ٣٠ and ٣٨ MPa .

٣- ٣- ٢ Mix propotions.

The proportions of the concrete mixes are summarized in Table (٣-٥) .

Table (٣-٥) : Mix proportions and slump of the concrete mixes.

Mix Proportions (kg/m٣)						
Series	W/C	Water	Cement	Sand	Gravel	Slump(mm)
A	٠.٤٥٧	٢٠٥	٤٤٨	٦٨٦	٩٦٦	٨٠-١٠٠
B	٠.٤	٢١٥	٥٣٨	٥٩٦	٩٦٦	٨٠-١٠٠

٣- ٤ Testing fresh and hardened concrete.

٣- ٤- ١ Slump Test.

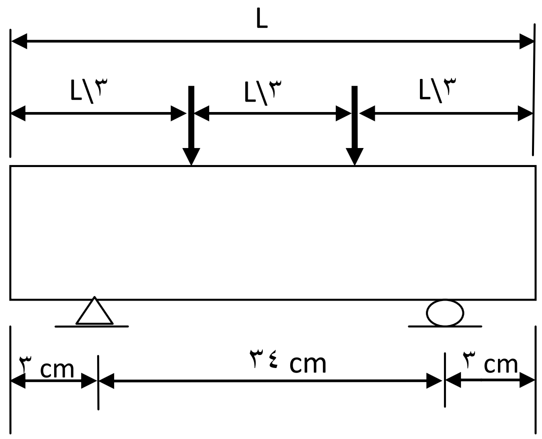
The workability of the fresh concrete mixes was measured by the slump test before casting these mixes in their moulds .This test was conducted according to ASTM C١٤٣-٨٩a:١٩٨٩ [٥٣]specification.

٣- ٤- ٢ Compressive Strength Test:

Compressive strength was carried out and tested according to BS ١٨٨١: part ١١٦:١٩٨٣[٥٤] . A cubes of (١٥٠) mm were tested by using a hydraulic compression machine of ٢٠٠٠ KN .Each compressive strength value was the average compressive strength of three cubes at age of ٢٨ days**.**

٣- ٤- ٣ Flexural Strength Test.

Concrete prisms of (١٠٠×١٠٠×٤٠٠mm) were cast for measuring flexural strength. The prisms were cast, demoulded and cured in a similar manner as for the slab specimens. Modulus of rupture test was performed according to ASTM C٢٩٣-٨٣[٥٥] procedure using two point loading as shown in plate (٣-١)and figure (٣-١). Each value of the modulus of rupture is the average of the test results of two prisms.



·   **Figure (٣-١): Two-point load flexural strength test.**

Each value of the modulus of rupture is the average of the test results for two specimens. Modulus of rupture is calculated from the simple beam bending formula [٥٥]:

R= pl / bd^{٢} ---------------(٣-١)

Where:

p=maximum applied load ,N , l=span length, mm

b=specimen width , mm , d=specimen depth, mm

This equation is valid only if failure line is within the middle third span. If failure line is outside middle span by not more than ٥ % of the span length, the equation below is used [٥٥] :

$R = ٣pa / bd^{٢}$ ------------(٣-٢)

Where:

a=the average distance between the point of fracture and the nearest support.

٣-٤-٤ Static Modulus of Elasticity Test.

The static modulus of elasticity was determined according to ASTMC-٤٦٩[٥٦] specification. A cylinders (١٥٠*٣٠٠) mm were tested. All specimens were castand cured as for the compressive strength cubes. A hydraulic compression machine of ٢٠٠٠ kN is used to apply a compression load until ٤٠ % of the ultimate load . The clamping rings used which have a gauge length of ٢٠٠ mm and gauge with an accuracy of ٠.٠١ mm,as shown in plate (٣-٢). The recorded results were the average of readings for two cylinders at age ٢٨ days. The modulus of elasticity is calculated as follows[٥٦] :

$E_c = (S_٢ - S_١) / (\varepsilon_2 - \varepsilon_1)$-----------(٣-٣)

Where:

E_c=modulus of elasticity GPa.

$S_٢$=stress corresponding to ٤٠ % of ultimate load GPa.

$S_١$=stress corresponding to the longitudinal strain of $٥٠*١٠^{-٦}$ GPa.

ε_2=longitudinal strain produced by $S_٢$.

$\varepsilon_1 = ٥٠*١٠^{-٦}$

٣-٤-٥ Ultrasonic Pulse Velocity (U.P.V)

The velocity of Ultrasonic Pulses transmitted through the reinforced concrete slab specimens was determined before and after burning. Ultrasonic Pulse transit times were measured by direct transmission method. This test was carried out according to ASTM C٥٩٧ [٥٧] . Portable ultrasonic concrete tester known as (PUNDIT) ٥٤ KHz was used for this purpose as shown in plate (٣-٣).

Pulse velocity ,V, in km/sec is calculated as follows :

V= L / T ------------(٣-٤)

Where :

V = Ultra-sonic pulse velocity, km/sec.

L = path length , mm .

T = transit time , microsecond.

٣-٤-٦ Schmidt Rebound Hammer Test

Schmidt Rebound hammer was used to estimate the hardness of concrete specimens by recording the rebound number , which could be used as a measure of the concrete strength and percentage of voids. The test method is prescribed by BS ١٨٨١: ٢٠٢:١٩٨٦[٥٨] specifications.The Schmidt hammer rebound number was recorded at ١٦ distributed points on the top unexposed face of the slab specimen. Schmidt hammer was used as shown in plate (٣-٤).

٣-٤-٧ Load - Deflection Test.

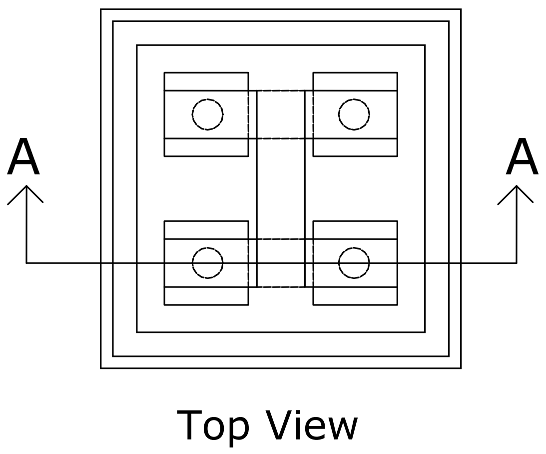
The slab specimens were tested in pressing machine. The steel support was used to represent the base of restrained slabs.

A load cell with capacity of (١٠٠ tons) was used to measure the load applied by a hydraulic Jack.

Steel loading base and ١٠٠mm layer of sand were used to transmitted the load from hydraulic Jack to the slab specimen as uniform distrited load [٥٩,٦٠].

The steal loading base transmitted the load from hydraulic Jack to ١٠٠ mm layer of sand used between the loading base and the slab specimen as shown in Figure(٣-٢).The steel loadin base consisted of three steel members with I-section, two of these members were paralled and the other welded perpendicularly upon them. The parallel steel members were connected to four steel legs,these legs were connected by welding to four steel plates,then, these plates were fixed over a steel plate of(٤٨٠×٤٨٠×٥mm) by welding .

A box of dimensions of (٥٢٠×٥٢٠×١٠٠mm), made of steel plate of thickness ٥mm opened from upper and lower square areas was used to hold the sand. Deflections were measured at load stages using a dial gauge with a capacity of (٢٥.٤mm) and accuracy of (٠.٠٢٥mm) at mid span of the slab specimens.



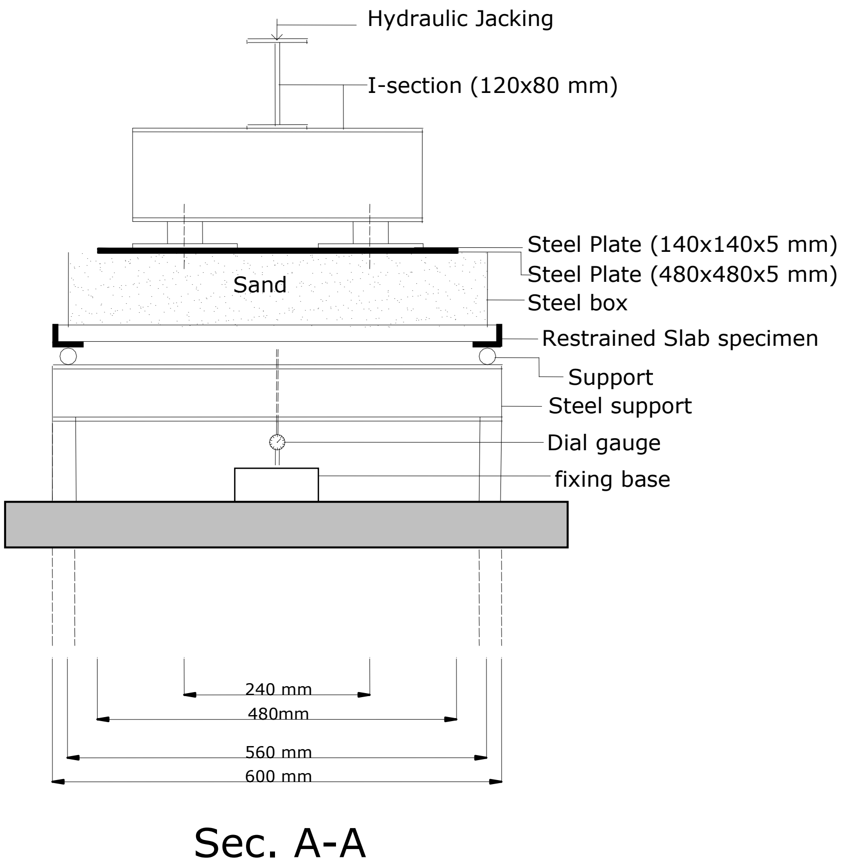


Figure (٣-٢) : Loading arrangement and test setup for uniform load flexure test.

٣- ٥ Casting Procedure of the Specimens

٣- ٥- ١ Mixing and Casting of Specimens.

The concrete was mixed using an electrical drum type mixer, with a capacity of ٠.١m^{٣}. The interior surface of mixer was cleaned and moistened

before placing the materials . Materials were put in the pan of the mixer ,firstly coars and fine aggregate were mixed together with small amount of mixing water .Cement and mixing water were added as mixing proceeded .By naked eye a homogeneous mix was observed . The total mixing time from the time of adding water was about ٣ min.Then the concrete mixes were cast in steel moulds to obtain a slab specimen with clear dimensions of (٦٠٠ × ٦٠٠ × ٤٠mm). With each casting process of slab specimen, three concrete cubes,two concrete cylinders and two concrete prisms were also cast. These specimens were subjected to the same conditions that the reinforced concrete slab specimens were subjected. The concrete mixes were cast in two layers,each layer was compacted by using a vibrating table for about ٣٠ second until no air bubbles emerged from the surface of the concrete.

٣- ٥- ٢ Curing and Exposure .

Polythene sheets were used to cover the upper surface of the specimens. Two days after casting, the specimens were demoulded and immersed in tap water until the age of ١٤ days ,and air dried in the laboratory for ١٤ days , then at age of ٢٨ days they were subjected to fire flame .

٣- ٦ Heating and Cooling Procedure.

The concrete specimens were burnt with direct fire flame from a net work of methane burners with dimentions of (١٠٠٠x١٠٠٠ mm) as shown in plate (٣-٥). The fire flame was intended to simulate the heating condition in as actual fire .The fire flame hits the lower face of the slab specimens as shown in plate (٣-٦). The intensity of the flame was adjusted to raise the specimens to different temperatures. When the target temperature was reached, the temperature was continuously measured by thermocouples, one of them was positioned in the bottom surface of the slab specimen in contact with the flame while the other was positioned at the unexposed upper surface to measure the temperature of the exposed surface and unexposed surface , The measurement devices are shown in plate (٣-٧).The duration of fire depends on the speed with which it can be put out .Total fire duration , including the time of the bulding –up of the fire , can vary from about one hour to about one day[١٣].However, for this work , it was decided that exposure time of one hour at the level of the maximum temperature would cover the range of situations occuring in the majority of elevated temperatures during fires [٦١,٦٢] . Although the maximum temperatures reached during fires of buildings are in the order of ١٠٠٠ to ١٢٠٠ °C [,٦٣] such high temperatures occur only at the surface of the exposed members. Considering the relatively small size modeling of the specimens tested, it was decided to limit the temperature of the specimens to three temperature levels of (٤٠٠, ٥٠٠ and ٦٠٠ °C). After burning, the reinforced concrete slab specimens were allowed to cool in the laboratory to the room temperature which is in the range of ٢٥ °C .

٣-٧ Testing Reinforced Comcrete Slabs.

٣-٧-١ Slab Specimens .

The chosen dimensions for the slabs were (٦٠٠*٦٠٠*٤٠mm)(length * width * thickness) respectively. The slab specimens were assumed to be partially restrained on the four edges.Sixteen slab specimens of were cast. These slab specimens were divided into two series A and B with two design compressive strengths (٣٠, ٣٨MPa) , and with two steel ratios of (٠.٠٠٥ , ٠.٠٠٩) respectively.Plain steel bars ٤ mm in diameter were used as reinforcement to test slab specimens. The reinforcement bars were cut to the desired length, then they were uniformly spaced and placed in two directions according to the limited distances of (٨٠ , ٤٥mm) to obtain the desired steel ratios of (٠.٠٠٥ , ٠.٠٠٩) respectively as shown in figure (٣-٣) . In order to get a constant clear cover, small pieces of steel of ٨ mm diameter were placed under the reinforcement.

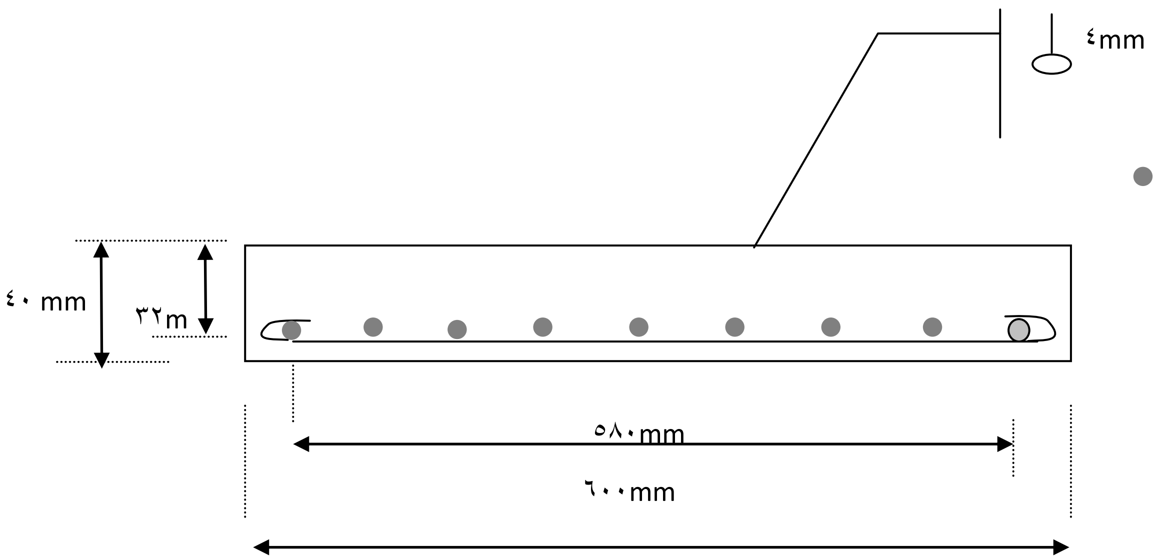


Figure (٣-٣): Details of reinforcement of the slab specimens.

٣- ٧- ٢ Partial Steel Restraining Frame

The plate edge restraining frame consists of four equal steel angles, each of size (٤٠ *٤٠ *٥ mm) ,welded together at right angles to form a square steel frame (٦٠٠*٦٠٠ mm) . Fig .(٣-٤) shows the dimensions of the plate edge restraining frame. The plate (slab) concrete specimen was put inside the steel restraining frame. To maintain a good contact between the plate edges and the steel frame the gap was filled with high strength cement paste. Three days later, the whole system (the steel restraining frame with the concrete plate inside)was moved to the testing machine to be tested in flexure [٥٠].

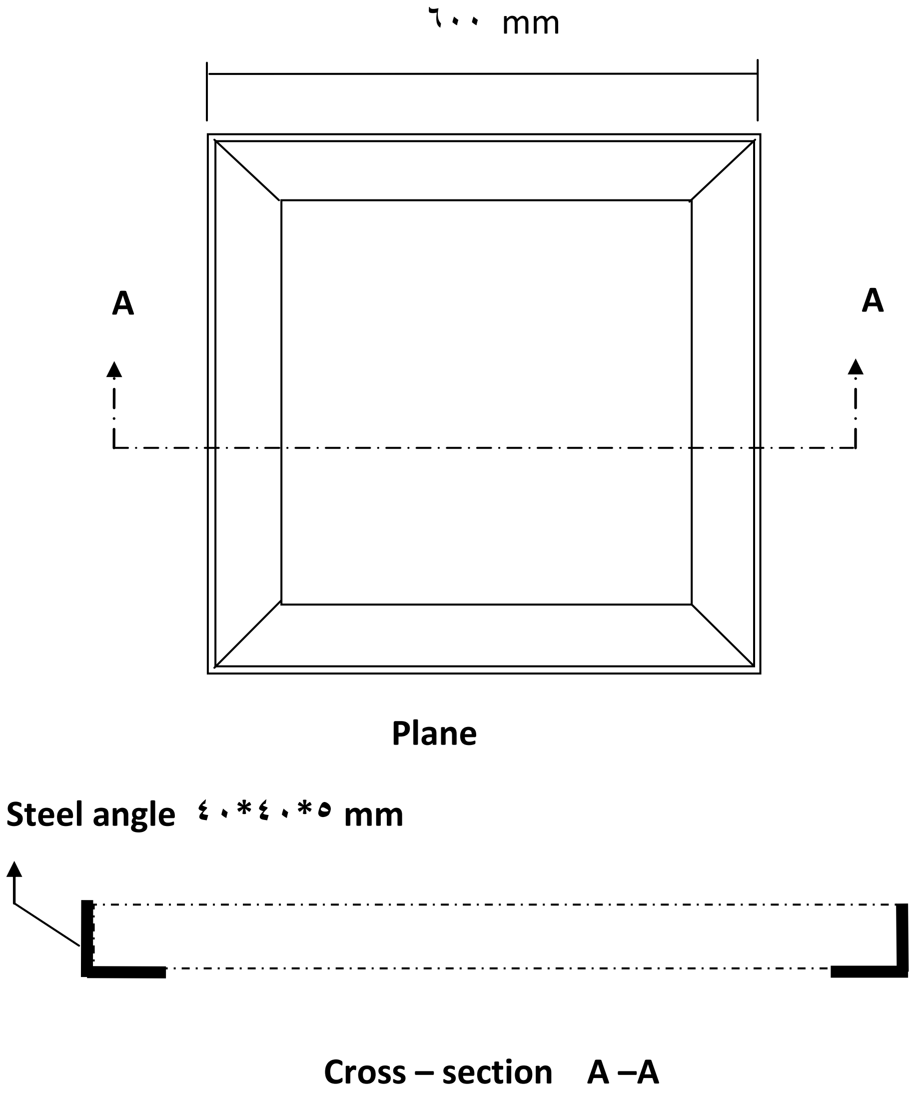


Figure . (٣-٤) : Details of the edge restrainingsteel frame

Plate (٣-١) : Flexural strength testing machine .

Plate (٣-٢):Test set –up of the modulus of elasticity .

Plate (٣-٣): Ultrasonic pulse transit time test .

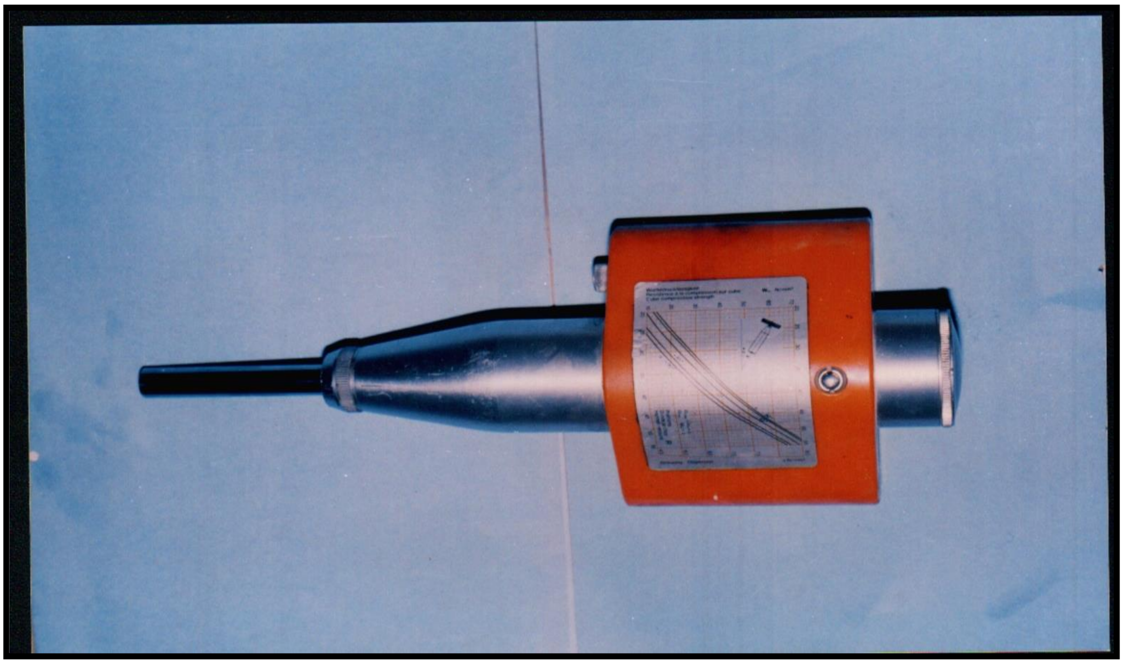


Plate (٣-٤) : Rebound hammer .

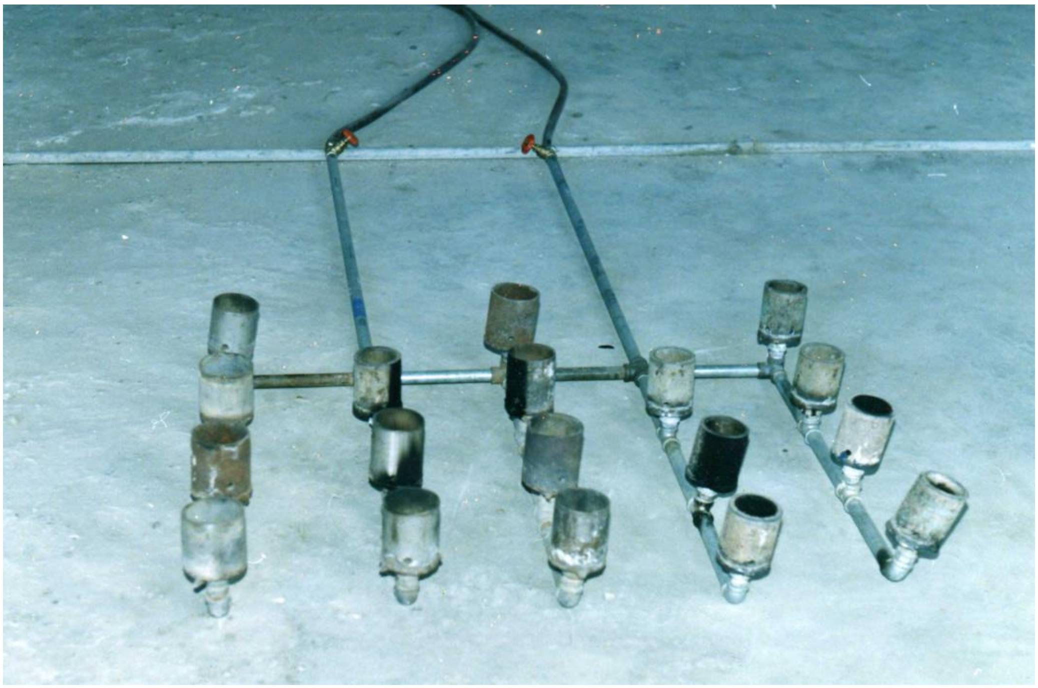


Plate (٣-٥) : The net work of methane burners .

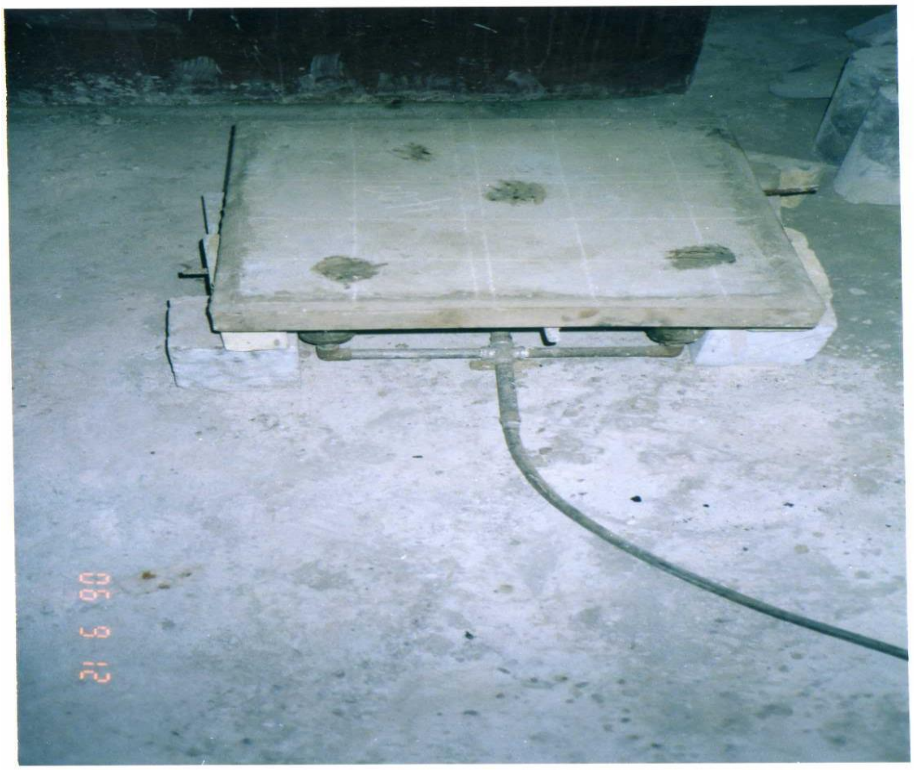


Plate (٣-٦) : Restrained slab specimen exposed to fire flame.

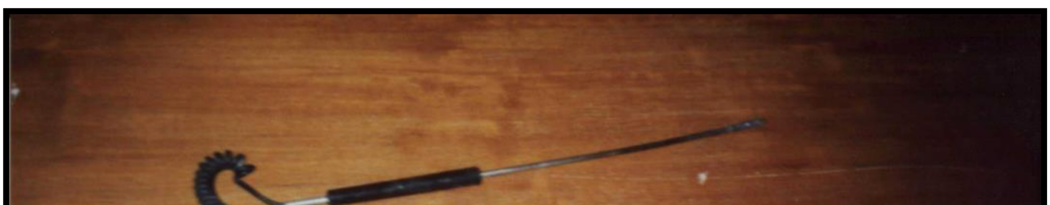


Plate (٣-٧) : Temperature measurement devices .