SEISMIC ANALYSIS OF TRADITIONAL JACK-ARCH SLAB IN SOUTH OF IRAQ

Dr.Abbas Oda Dawood
abbasoda03@yahoo.com

Dr.Sa'ad Fahad Resan
sadresan@uomisan.edu.iq

Department of Civil Engineering
Engineering College
University of Misan
Amarah, Iraq

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ABSTRACT

Jack arch slab is still widely used southern Iraq although it is old roof system due to number of practical and economical advantages including simple construction technique, speed in construction, low cost availability of local labor skills. The study of seismic performance of this roofs in south of Iraq is important due to the last earthquakes activity in Iraq and relatively high earthquakes magnitudes of about 6 degrees according to Richter scale, especially in Misan Province. Static tests were conducted to determine the properties of clay brick and gypsum mortar used for jack arch slab in south of Iraq, then the properties of masonry unit is obtained. The effect of camber configuration on ultimate strength and maximum deflection for both flat and 2 cm camber masonry arch specimens is investigated experimentally. The horizontal seismic loads is determined according to UBC while detailed procedure to determine vertical seismic load according to both UBC and Iranian codes is presented due to its govern the design. Finite element numerical analyses are then conducted using STAADPRO software to investigate the effects of a seismic loads on the behavior of slab and evaluate the safety of this type of roofs when subjected to seismic load. It is concluded that the flexural stresses are govern the behavior of jack arch slab not membrane stresses. Based on finite element analysis, the compressive stresses developed in the slab are less than allowable stress but tensile stresses is critical, also the deflection and stresses of IPE steel beams is not exceed the allowable limits.

KEYWORDS: Jack arch slab; seismic analysis, vertical component, camber, flat slab, masonry

التحليل الزلزالي لسقوف العقادة التقليدية في جنوب العراق

د.عباس عوده داود **د.سعد فهد رسن**

جامعة ميسان/كلية الهندسة/ قسم الهندسة المدنية

الخلاصة

سقوف العقادة لازالت واسعة الاستعمال جنوبي العراق على الرغم من كونها نظام تسقيف قديم و ذلك يعود لعدة مزايا تنفيذية و اقتصادية و التي تتضمن بساطة طريقة التنفيذ و سرعة التنفيذ و الكلفة الواطئة و توفر العمالة الماهرة لها محليا. إن دراسة السلوك الزلزالي هذا النوع من السقوف جنوبي العراق مهم و ذلك للنشاط الزلزالي المتزايد في السنوات المنصرمة في العراق و الدرجة الزلزالية العالية نسبيا و التي بلغت 6 درجات على مقياس ريختر و خصوصا في محافظة ميسان. تم إجراء الفحوص الاستاتيكية لتحديد

خواص الطابوق الطيني و مونة الجص المستخدمة في إنشاء سقوف العقادة جنوبي العراق, و منها تم تحديد خواص العقادة نظريا. تم التحري العملي لتأثير التقوس على قابلية التحمل و الهطول الأعظم لكل نموذج من العقادة المقوس و المستوي. تم حساب المركبة الأفقية لقوى الزلازل وفقا للمدونة UBC بينما تم حساب المركبة الشاقولية لقوى للزلازل وفقا للمدونة UBC و المدونة الإيرانية كونها هي المركبة المسيطرة في التصميم. تم إجراء التحليل العددي بطريقة العناصر المحددة باستعمال برنامج الحاسبة STAADPRO لتحري تأثير قوى الزلازل على تصرف سقوف العقادة و سلامة تلك السقوف عند تعرضها للزلازل. تم استنتاج إن اجهادات الانحناء هي المسيطرة على سلوك سقف العقادة وليس الأجهادات الغشائية. استناد إلى نتائج تحليل العناصر المحددة فان اجهادات الانضغاط المتولدة اقل من الحدود المسموحة و لكن اجهادات الشد حرجة. كذلك فان هطول الجسور الحديدية الحاملة للعقادة و الأجهادات المتولدة فيها هي ضمن الحدود المسموحة.

1. INTRODUCTION

The primary function of floor and roof systems is to support gravity loads and to transfer these loads to other structural members such as columns and walls. Furthermore, they play a central role in the distribution of wind and seismic forces to the vertical elements of the lateral load resisting system (such as frames and structural walls).The horizontal forces generated by earthquake excitations are transferred to the ground by the vertical systems of the building which are designed for lateral load resistance (e.g. frames, bracing, and walls). These vertical systems are generally tied together as a unit by means of the building floors and roof. In this sense, the floor/roof structural systems, used primarily to create enclosures and resist gravity (or out of plane) loads are also designed as horizontal diaphragms to resist and to transfer horizontal (or in-plane) loads to the appropriate vertical elements (**Naeim and Boppana, 2001)**.

The manner in which the total shear force is distributed to the vertical elements (walls) depends on the wall rigidity relative to the diaphragm rigidity. In buildings with flexible diaphragms, the distribution of shear forces to walls is independent of their relative rigidity. These diaphragms act like a series of simple horizontal beams spanning between the walls. A flexible diaphragm must have adequate strength to transfer the shear forces to the walls, but cannot distribute torsional forces to the walls in the direction perpendicular to the earthquake ground motion **(EERI, 2011)**.

For design purposes, diaphragms are usually treated either as flexible or rigid. It is general practice to consider the diaphragms made of cast in place concrete, precast with concrete topping, and metal deck with concrete fill as rigid while the diaphragms consisting of precast planks without concrete topping, metal deck without concrete fill, and plywood sheathing as flexible. Obviously, a flexible diaphragm can not experience the rotation or torsion that occurs due to the rigid body rotation of a rigid diaphragm **(Naeim and Boppana, 2001).**

2. JACK ARCH SLAB

The traditional steel I-beam, jack arch flooring system was developed in Britain towards the end of nineteenth century and was used extensively to cover large floor areas in factories and other industrial buildings. The technique spread eastwards and, by the middle of the twentieth century, it became a popular flooring system in parts of East Europe, the Middle East and the Indian subcontinent. Due to its technical simplicity, speed in construction and low cost, traditional jack arch slabs are still very popular in the Middle East, where, not only industrial buildings and ordinary dwellings but also many high-rise steel and concrete framed buildings are floored by this method **(Maheri and Rahmani, 2003)**.

Jack arch slab is steel beams that are covered by brick arches. They were used extensively in previous decades in Iraq, Iran and other countries. The results of past earthquakes in Iran like Boin Zahra.1962, Dashte bayaz.1968, Rudbar.1990, Bam 2003 showed that lack of integrity and rigidity are the main deficiencies of this slab. Moreover, this slab should be assigned to the flexible diaphragms based on Iranian standard code No.2800 **(Mahdizadeh at al, 2012)**. The roofs and floors, which are rigid and flat and are bonded or tied to the masonry, have a positive effect on the wall, such as the slab or slab and beam construction be directly cast over the walls or jack arch floors or roofs provided with horizontal ties and laid over the masonry walls through good quality mortar. Others that simply rest on the masonry walls will offer resistance to relative motion only through friction, which may or may not be adequate depending on the earthquake intensity **(IAEE, 1986)**.

Customary jack arch slab in south of Iraq consists steel I-beam commonly IPE 120, and brick jack arch. The maximum span of I-beam is 4 m and the spacing between I-beams (jack arch span) is between 0.7m to 0.9 m (commonly 0.8m) as shown in **Figure (1)**. The mortar used in brick work is gypsum mortar. The interior face of the slab is covered by cement plastering while the exterior face is firstly covered by thin layer of gypsum mortar, then water proof thin sheets, then clean clayey soil layer sloped to discharge rain water.

2.1. Behavior of Jack Arch Slab

The floor slabs constructed using the steel I-beam jack arch system are stable under normal static conditions as the brick arches transfer the gravity loads, mainly in compression, along the arch to the supporting beams, **Figure (2)**. The load is then transferred along the parallel steel beams to the supporting walls or beams. The geometric form of the steel I-beam jack arch system and the load path through the steel beams, make the slab act as a one-way system**.**

Despite the wide spread use of the jack arch slabs and their advantages, there are no particular procedures for their engineered design and there is no mention of the system in codes of practice. Indeed, a search of the literature reveals no reference to any particular scientific research directed at studying this slab system or any attempts to provide an engineering basis for its design and construction. Design engineers, using the jack arch slab in framed buildings, consider the brick arches as merely dead loads, carried by the steel beams, and are sufficient in designing the steel beams. This assumption ignores the role of brick arches in transferring slab loads and the resulting large stresses developed in them. Despite the lack of a proper design basis and the poor performance of the jack arch system under earthquake loading, this type of flooring is still used extensively in many countries. The reason for this being a number of practical and economical advantages including simple construction technique, speed in construction, low cost and the ability to alter the slab after construction, when compared to conventional reinforced concrete or concrete beam-block slabs. The performance of the traditional one-way jack arch slab in a number of recent earthquakes in Eastern Europe and the Middle East, particularly in Iran, has generally been poor. Collapse of a large number of jack arch slabs and damage to many more was reported from the Romanian earthquake of 1990 **(Maheri and Rahmani, 2003)**.

3. EXPERIMENTAL WORK TO DETERMINE MATERIAL PROPERTIES OF JACK ARCH SLAB

No data on the strength and mechanical properties of the local type of masonry were available. For this reason, standard static tests were carried out on brick units, mortar and masonry. The Experimental work consisted of two phases, the phase I which is concerned with physical and mechanical properties of used materials to supply sufficient information about local materials which are used to manufactured Jack arch slab in Iraq. Phase II related to testing strength of typical one way masonry arch specimens which commonly used in practice in south of Iraq nowadays.

3.1 Material Properties of Brick and Mortar

The brick arches in south of Iraq consists of local clay bricks joined together by a gypsum mortar. Gypsum is a very soft sulfate mineral composed of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$).The gypsum mortar composed of gypsum mixed with water. It is one of the oldest known types of mortar in Iraq due to availability of its raw materials. It is the only mortar used for jack arch construction in Iraq because it sets hard and quickly. Clay bricks are the most commonly types of bricks in Iraq because of availability of raw materials, low cost of production, appropriate to bear the forces, heat isolation, resistance to fire and atmospheric changes, their standard dimensions are (240 mm x 115mm x 75mm) according to Iraqi specifications **(IS25, 2000)**.

For gypsum mortar the tests are included mechanical and physical properties due to lack of data for this type of mortar in the literature. A cubes of 50*50*50 mm were used to measure the compressive strength in which an average value of 3 MPa was obtained. Modulus of rupture was obtained by testing a prisms of dimensions 40*40*160mm in whcih an avergae value of 0.466 MPa was obtained. The modulus of elasticity of gypsum mortar is measured experimentally as the slope of the linear portion of stress-strain curve, which is equal to 1000 MPa, as shown in **Figure (3)**.

The tests of bricks is limited to compressive strength and density due to good literature are available to find other properties like modulus of elasticity. The average compressive strength of clay brick is 10 MPa and the density is 1665 Kg/m^3. The Modulus of elasticity for clay solid brick can be determined from available strain-stress curves in the literatures. Kaushik et al **(Kaushik et al, 2007)**, presented equation Eq.(1) to determine the modulus of elasticity of clay brick in term of compressive strength of the brick, Thus according to Eq.(1), for f_b=10 MPa, then E_b= 10*300=3000MPa.

$$E_b \approx 300 f_b \tag{1}$$

3.2 Material Properties of Masonry

Two specimens were fabricated and experimentally investigated to highlight the effectiveness of camber, the first one with camber of 2cm and the second with zero camber (flat). Both specimens have length of 70 cm and width of 32 cm. A workable Gypsum mixture is used to bind units together and fill the gaps between them. The inner face of the slab is finished with plaster layer from cement -sand mortar of ratio 1:3 (cement to sand) as commonly used in practice.

For masonry unit (both bricks and mortar) the flexural bond strength between brick and mortar is investigated according to procedure used by **(Khalaf, 2005),** see **Fig. (3)**. The average tensile bonding strength between clay bricks and gypsum mortar obtained from tests is 0.332 MPa.
All one way masonry arch elements were tested under three-point load test, in which all loads were applied at mid-span of specimens. Load was applied at the mid-span of the slab using a hydraulic jack having a capacity of 10 Ton. The slab was simply supported at its ends. Dial gauge was placed on the mid-points of mid span of the slab to measure the deflection as shown in **Fig. (4).**

The effectiveness of jack arch slab camber is investigated through both specimen's strength and deflection. The failure load and maximum mid-span deflection of camber slab is 3.554 MPa and 0.82 mm respectively, while for flat slab, the failure load and maximum mid-span deflection is 3.358 MPa and 1.184 mm respectively. The experimental results showed that for relatively small camber the strength was increased and the deflection was decreased which mean that jack arch slab performance could be improved by increasing it crown camber. There is one failure mode for both specimens camber and flat, its characterized by suddenly flexural collapse of masonry arch.

4. THEORETICAL ESTIMATION OF MASONRY PROPERTIES

4.1 Theoretical Estimation Of Masonry Compression Strength, F'm

f'_M is the intrinsic property of masonry which can be used in the design of a variety of masonry elements. f'm is also used to estimate Em and for plotting the masonry stress-strain curves. Therefore, f'm is one of the most basic and required properties which must always be available for a given masonry. However, it is not always feasible to conduct compression testing of masonry prisms. On the other hand, fb and f j are readily available in the design codes or can be obtained easily by conducting tests. The three compressive strengths can be conveniently related as done in Eurocode6 as **(Kaushik et al, 2007)**:

$$f'_M = K f_b^{\alpha}\ f_m^{\beta} \tag{2}$$

where fb : compressive strength of bricks, MPa; fm: compressive strength of mortar, MPa;f'M : compressive prism strength of masonry, MPa; K: constant depending upon brick properties and brick-mortar joint configuration; α, β: constants representing contribution of bricks and mortar compressive strengths on f'M

Kaushik et al **(Kaushik et al, 2007)**, proposed the following equation to estimate the masonry prism compressive strength from the compressive strengths of bricks and mortar obtained experimentally.

$$f'_M = 0.63 f_b^{0.49}\ f_m^{0.32} \tag{3}$$

They found that Equation proposed by Eurocode6 **Eq.(2)**, is good for masonry constructed with high strength bricks, however for lower strength bricks, the error in estimating the masonry compressive strength is comparatively higher. The estimation of masonry compressive strength using **Eq.(3)** proposed in their study is consistently better for prisms made with low and medium strength bricks. Thus in the present study masonry compressive strength is determined using **Eq. (3)**. Thus for f_b=10 MPa and f_m=3, then $f'_M = 0.63*10^{0.49} * 3^{0.32} = 2.77\ MPa$

4.2 Theoretical Estimation of Masonry Modulus of Elasticity and Poisson's Ratio

The modulus of elasticity of masonry depends on the modulus of elasticity of the mortar and the unit as well as the volumetric ratios of the constituent materials. In reality, the modulus of elasticity of masonry varies for different directions and loading conditions **(**ÖZEN**, 2006)**. Empirical linear relationships between the compressive elastic modulus and the equivalent compressive strength from some researchers are usually assumed as follows **(Wijanto, 2007)**

$$E_M = k f'_M \tag{4}$$

Where k is a constant factor, EM is elastic modulus of masonry in compression (MPa) and f'M is specified compressive strength of masonry (MPa). k factor for clay bricks varies from 300 ≤ k ≤ 750.

This huge range factor is depend on the local raw material of clay brick **(Wijanto, 2007)**. Some methods relate the modulus of elasticity of masonry to the masonry geometry and the material properties. One of these methods is **(**ÖZEN**, 2006)**:

$$\frac{1}{E_M}=\frac{\eta_b}{E_b}+\frac{\eta_m}{E_m}+2\eta_m\eta_b\frac{\nu_b E_m-\nu_m E_b}{\eta_m(1-\nu_b)E_m+\eta_b(1-\nu_m)E_b}\left(\frac{\nu_m}{E_m^2}-\frac{\nu_b}{E_b^2}\right) \tag{5}$$

where, η_m, η_b : are the volume fractions of mortar and brick, E_M : is the modulus of elasticity of the masonry, E_b, E_m: are the modulus of elasticity of the brick and the mortar, ν_b, ν_m: are the Poisson's Ratio of the brick and the mortar. The volume fractions of the brick and the mortar can be calculated by using the following equations;

$$\eta_m=\frac{t_m}{t_b+t_m}\ ,\ \eta_b=\frac{t_b}{t_b+t_m} \tag{6}$$

Where, t_m: is the thickness of the mortar, t_b: is the thickness of the brick. In present study the modulus of elasticity of masonry is determined suing **Eq. (5)** due availability of experimental data for brick and gypsum mortar. Thus for E_b=3000 MPa and E_m=1000 MPa, then E_M=2586 MPa.

Poisson's ratio of most hydraulic cement and lime mortars is on the order of 0.2 **(Wijanto, 2007)**. **Francis et al (Francis et al, 1971)**obtained the value of Poisson's ratio of 0.25 for both solid and perforated clay bricks . The Poisson's Ratio of masonry is generally between 0.2-0.25 **(**ÖZEN**, 2006)**. In present study a Poisson's ratio of 0.2 , 0.25, 0.22 is used for mortar, clay brick and masonry respectively.

5. ALLOWABLE STRESSES OF JACK ARCH SLAB

The failure for the jack arch slab is either failure of steel beams or failure of brick arches. The bending failure of the steel beams is govern its behavior. The compressive failure of the brick arches is govern if the there is suitable camber, so that brick arches transfer the load to steel beam by arches compression action in which membrane stresses developed in the brick arches. In traditional jack arch slabs in southern Iraq it is either flat slab or with relatively small camber of 2 cm, so that the brick arches behave as bending plate and the flexural stresses is govern it is behavior. The flexural failure was govern the jack arch slab behavior which is clearly appear in the experimental investigation of tested specimens, in which the failure of specimens were mainly due to bottom tensile stresses. The arches were not reached to the compressive capacity which mean that the compressive membrane stresses are low .

To investigate the stress distribution of experimentally tested specimens, a three dimensional finite element model for jack arch slabs (flat and camber) at failure loading conditions was accomplished. The stress distribution of flat and camber slabs at failure loads are shown in **Fig. (5),** in which the flexural stresses are govern in both flat and camber slabs. In flat slab membrane stresses is zero while in camber flat there is relatively low membrane stresses in comparison with flexural stresses . The distribution of stresses shown in **Fig. (5)**, is compressive stresses at top and tensile stresses at bottom with maximum values at mid-span.

The allowable compressive stress for flat jack arch slab is assumed as given by UBC code **(UBC, 1997)** for masonry wall, namely:

$$f_{m,all} = 0.16\ f'_M \tag{7}$$

While for jack arch slab with camber, due to the loading situation and the geometry of the arch, an increase in compressive stress (increase in load) will cause an increase in the stability of the arch. For this reason, **(Maheri and Rahmani, 2003)** proposed that the allowable compressive strength for jack-arch construction could be found from the following equation.

$$f_{m,all} = 0.2\ f'_M \tag{8}$$

The tensile failure in brick arches is governed by the bond tensile strength in case of slab with camber. While in case of flat slab the tensile flexural strength is govern. Thus for camber slabs the tensile strength is 0.332 MPa based on bond strength obtained experimentally. while for flat slabs the allowable tensile stress for can be determined indirectly from flexural tests results, in which flexural tensile strength is 0.327 MPa. Thus an average value has been taken, then tensile strength for both camber and flat slab is 0.33 MPa, then the allowable tensile stress is

$$f_{t,all} = 0.33\ \text{MPa} \tag{9}$$

The allowable stresses for steel is determined by codes of practice namely AISC-ASD **(AISC, 2006)**, in which allowable flexural tensile or compressive stress for steel is assumed to be:

$$f_{s,all} = 0.6\ f_y \tag{10}$$

Thus the compressive allowable stresses for f'_M=2.77MPa, is 0.443 MPa and 0.554 for flat and camber slabs respectively, the allowable tensile stress is 0.33 MPa for both slabs, while for steel beams the allowable stress is 140 MPa.

6. LOADING

Loading to be considered in the design of jack arch slabs, are gravity and earthquake loads. The masonry is very strong under compression forces therefore, masonry structures are usually very resistant to gravity loads. Earthquake loads and differential settlements of supports are usually the main reasons for the damage or collapse of masonry structures **(**ÖZEN**, 2006)**.

The gravity, service dead and live loads may be determined using appropriate codes of practice, according to Iraqi Code for Loads and Forces **(IS301, 2014),** a live of 1 KN/m2 is appropriate for jack arch slab buildings. The earthquake loads, acting on a jack arch slab are in-plane horizontal loads and out of plane vertical loads. In the present study the horizontal and vertical earthquake loads are determined using equivalent-static method.

Load combinations for allowable stress analysis based on UBC code **(UBC, 1997)** is given in **Eq.(11)**, in which worst case should be considered in design.

$$D + L$$

$$D + L + \frac{E}{1.4} \tag{11}$$

$$0.9D \pm \frac{E}{1.4}$$

The earthquake have two components horizontal and vertical. The earthquake-induced horizontal forces acting on the slab may be either in-plane axial or in-plane shear forces as shown in **Fig. (6).** The majority of stresses developed in the slab are due to the combined effects of gravity and vertical earthquake load.

7. DETERMINATION OF EARTHQUAKES LOADINGS BY EQUIVALENT STATIC METHOD

There is no specific criteria for seismic loadings on jack arch slab in codes of practice. Thus several modifications will be accomplished on codes procedures to take into account jack arch slab properties especially in vertical earthquake loadings. From these procedures and based on materials properties measured, the seismic loads on jack arch slab in south of Iraq are determined.

The horizontal and vertical earthquake loads are determined by equivalent-static method using procedures of UBC 1997. A modifications has been accomplished to determine the vertical earthquakes loads on jack arch slab based on UBC 1997. Also the vertical loads on jack arch slab is determined using procedure presented by Maheri and Rahmani **(Maheri and Rahmani, 2003)** which is based on Iranian Seismic Code. Maysan province lies on the Iraq-Iran borders therefore, seismic design data like peak acceleration could be obtained from Iranian seismic code.

7.1 Determination Of Horizontal Earthquakes Loadings By UBC 1997 Procedure

According to UBC 1997 **(UBC, 1997)** section 1653, Baghdad area is considered as Seismic Zone 3 while Basra as Zone 2. Because Maysan province has seismic hazards in last years more than Baghdad, thus according to UBC classifications Maysan province is considered as Seismic Zone 3. All jack arch buildings in Iraq either one-story buildings or two-stories buildings , Thus the equivalent static lateral-force procedure (UBC 97 Sec.1630.2) can be used to determine the seismic loads.

The total design base shear (V) in a given direction shall be determined from the following formula (UBC 97 sec.1630.2.3.2):

$$V = \frac{C_v\ I}{R\ T}\ W \tag{12}$$

The total design base shear need not exceed the following:

$$V = \frac{2.5\ C_a\ I}{R}\ W \tag{13}$$

The total design base shear shall not be less than the following:

$$V = 0.11\, C_a\, I W \tag{14}$$

Where C_a and C_v are seismic coefficients defined in Tables 16-Q and 16-R of UBC97 respectively (Ca and Cv for Zone 3 and Maysan soil type is equal to 0.36 and 0.57, respectively). Maysan Soil type is considered as SD type according to UBC classifications (Table 16-J UBC97). , I is occupancy important factor (I=1, Table 16-K UBC97), R is a factor defined in Table 16-N, T is fundamental time period and W total weight of structure.

For jack arch slab problems in south of Iraq **Eq (13)** is govern due to low rise building with this type of construction. The forces at each level shall be calculated using the following formula:

$$F_x = \frac{V w_x\, h_x}{\sum_{i=1}^{n} w_i\, h_i} \tag{15}$$

where w_x , w_i are portion of W located at or assigned to level i or x, respectively and h_x , h_i height in feet (m) above the base to Level i or x, respectively.

Seismic forces on floor and roof diaphragm Fpx at level x is determined from following equation (UBC sec. 1633.2.9)

$$F_{px} = \frac{F_t + \sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px} \tag{16}$$

where Fx , Fi are design seismic force applied to Level i, or x, respectively, $F_t = 0$ for $T < 0.7$ sec.
Also UBC specify the following limits on Fpx

$$0.5\, C_a\, I\, w_{px} \le F_{px} \le 1.0\, C_a\, I\, w_{px} \tag{17}$$

The weight, wpx , includes the weight of the diaphragm plus the tributary weight of elements normal to the diaphragm that are one-half story height below and above the diaphragm level. Walls parallel to the direction of the seismic forces are usually not considered in the determination of the tributary roof weight because these walls do not obtain support in the direction of the force, from the roof diaphragm **(SEAOC, 1999)**.

According to UBC code Table 16-N the R-factor for masonry bearing wall building (with masonry shear walls as lateral force resistance system) is equal to 4.5, but in section1633.2.9 of UBC code R-factor should not exceeding 4 for flexible diaphragms providing lateral supports for walls or frames of masonry or concrete. Thus for jack arch slab which consider as flexible diaphragm the R= 4. For a customary jack arch buildings in south of Iraq building have similar structural systems along different plan axes (i.e., directions) of the building in which the buildings have masonry shear walls in both directions. Therefore *R* have the same value in both directions. The structural period T may be approximated from the following formula:

$$T = C_t \ I \left(h_n\right)^{3/4} \tag{18}$$

where Ct = 0.0488 for jack arch slab, h_n = height in meter above the base to Level n. Total weight of structure, W, is the total dead load and applicable portions of other loads. Thus according to **Eq. (13)** the total design Horizontal base shear in a given direction, in term of seismic dead load, W, is summarized in **Table (1).**

7.2 Determination Of Vertical Earthquakes Loadings By UBC 1997 Procedure

The total design vertical earthquake load can be determined using the same equations for horizontal loads **Eq. (13)**, but using the following modifications for some parameters.
C_a and C_v coefficients are determined for the horizontal earthquake loading, thus it should be modified for the vertical loading. Design seismic vertical acceleration parameters can considered as 2/3 from horizontal acceleration parameters.

R is numerical coefficient depends on lateral force-resisting systems **(UBC, 1997)**, thus for horizontal load it can be easily found from UBC code (Table 16-N, UBC). But for jack arch slab, R, should be modified. The jack arch slab system may be considered as a confined masonry construction. For confined masonry walls, a value of 4 is often used for R factor, but the jack arch slab system is expected to behave differently to a conventional masonry building system. Maheri and Rahmani **(Maheri and Rahmani, 2003)** derived an approximate value for R for one-way and two-way jack arch slab based on UBC code formats. They concluded R = 2.0 may be considered for one-way jack arch slab system [1]. Thus here R taken to be equal to 2.0 for vertical loadings calculations. The design vertical component of seismic loads is summarized in **Table (1).**

7.3 Vertical Earthquake Force on Jack Arch Slab Using Iranian Code Procedure

This procedure is proposed by Maheri and **Rahmani (Maheri and Rahmani, 2003)** based on Iranian seismic Code **(Iranian Code, 2007)** using equivalent-static method (in this study this procedure is referred to as Iranian procedure). They proposed specific values for seismic parameters to be applicable for jack arch slab buildings. Their procedure is summarized as following.

This method is based on Iranian seismic code, the earthquake load, E, is related to the weight of the system, W_e, in the following form:

$$E = C \ W_e \tag{19}$$

W_e, is usually considered as the total dead load plus a percentage of the live load. The earthquake coefficient, C, may be determined from the relation:

$$C = \frac{A \ B \ I}{R_w} \tag{20}$$

in which, A, B, I and R_w are the design base acceleration, the dynamic response coefficient, the importance factor and the performance factor, respectively. They considered the performance factor, Rw, for the one-way system as 2.0 **(Maheri and Rahmani, 2003)**. For design of jack arch slabs, the importance factor, I, may be taken as that for the whole building.
The design base acceleration, A, is given by seismic codes for different localities. This coefficient is, however, determined for the horizontal earthquake loading and should be modified for the vertical loading. A 33% reduction is often used for this conversion.
For jack arch slab, the fundamental mode of vibration is considered for the first out-of-plane bending mode. They determined structural period T, for the jack arch slabs, by assuming the slab as a linear, elastic rectangular plate bending element, the classic solution for the fundamental bending mode of vibration is given in the following form **(Maheri and Rahmani, 2003)**:

$$T = \frac{2\pi\, a^2}{\lambda_1^2 \sqrt{\dfrac{E_{eff}\; h^3}{12\,\rho\,(1 - v_m^2}}} \tag{21}$$

In the above equation, a, h, E_{eff} , ρ and v_m are length, thickness, effective elastic modulus, mass per unit area and Poisson's ratio of the plate, respectively and λ_1 is a dimensionless parameter depending on the geometry of plate and its boundary conditions. To be able to apply this equation to a non-homogenous composite plate, such as a jack arch slab, they used equivalent effective parameters. The effective thickness, h, is considered as the full thickness of the flat slab, including flooring and the effective density, ρ , determined considering slab materials.. Poisson's ratio is considered to be the same as that for masonry due to the effect of Poisson's ratio is small.

The effective elastic modulus, E_{eff}, of the slab has an appreciable effect on the fundamental period of vibration. The parameters affecting the E_{eff} of the slab are the dimensions and boundary conditions of the slab, the elastic modulus of brick arches and the number, and size and configuration of the steel beams.

They found that the effective elastic modulus of slab, E_{eff}, is linearly proportional to the elastic modulus of masonry, E_M. As for the slab boundary conditions, the results from the worse case scenario, i.e. the simply supported situation, are used. The best parameter to represent the other two variables, i.e. dimensions of the slab and steel grid configuration, is the weight of steel per unit area of slab, *Ws* (kg/m^2). The results of these analyses are plotted in **Fig. (7).** In this figure, the ratio of effective elastic modulus of slab to elastic modulus of masonry (E_{eff}/E_M) is plotted against *Ws.*

The dynamic response coefficient, B, could determined from the diagram given by the Iranian Seismic Code which shown in **Fig. (8).** The actual values of B for the four different soil types are calculated and plotted, in the **Fig. (8).** According to Iranian code Maysan province soil can be consider as Type III.The design vertical component of seismic loads for both UBC and Iranian procedure is summarized in **Table (1).**

8. FINITE ELEMENT INVESTIGATION OF JACK ARCH SLABS

To investigate the behavior of the jack arch system in south of Iraq, a finite element models were accomplished to represent the real systems for both flat slabs and slabs with 2 cm camber. The finite element linear stress analyses of the slabs were carried out using the general-purpose, STAADPRO

program **(STAAD PRO, 2008)** Beam elements were used to model beams and shell elements were utilized to model the brick arches. The dimensions investigated roof has steel beams of 4m span as commonly used southern Iraq, the spacing between steel beams is 0.7m, and roof dimensions 3.5m*4m. Dead load includes masonry slab weight, steel beam weight, and roofing weight. Live load is taken as 1 KN/m^2 which suitable for this construction. In calculation horizontal seismic loads the total weight W according to UBC code is equal to dead load plus half weight of normal walls for each direction X and Z. In calculation vertical seismic component (Y-direction) only dead load of slab is considered according to UBC procedure while adding 20% of live according to Iranian procedure.
The analyses were accomplished for all possible loads combinations as shown in **Table (2)**. The typical stress contour for both flat and camber jack ach slabs are shown in **Fig. (9)**.
From the results of internal stresses of jack arch slab shown in **Table (2)** it is clearly that the vertical component of seismic load is govern the design of jack arch slab.

The horizontal components of seismic loads have small influence on the behavior of jack arch slab as shown in **Table (2)**. The maximum compressive stress in case of horizontal seismic load in X-direction (normal to steel beams) in increased by about 3.5% more than gravity stresses for both flat and camber jack arch slabs, while the maximum tensile stresses is increased by about 3.5% more than gravity stresses for flat slab and stay equals for camber slab. In case of horizontal seismic load in Z-direction (paralell to steel beams), the maximum compressive stress in increased by about 6.7% and 3.5% more than gravity stresses for flat and camber jack arch slabs respectively, while the maximum tensile stresses is decreased by about 3.6% and 7.4% less than gravity stresses for flat and camber jack arch slabs respectively.

The maximum stresses developed in steel IPE beams is 69 MPa which is much less than the allowable stresses (140 MPa), also the maximum mid-spa deflection of steel beams is 7.7 mm which much less than maximum allowable out-of-plane deflection (L/360 =4000/360 = 11.11 mm). Thus the steel beam deflections and stresses is not critical in traditional jack arch system in south of Iraq under both gravity and seismic loads. Thus the critical part of jack arch slab is masonry arches.

Thus the critical case of seismic ad gravity combinations is vertical components of earthquake with dead load combinations. The maximum tensile stresses in case of vertical seismic component and dead according to UBC code procedure is more than gravity stresses by 25% and about 19% for flat and camber jack arch slabs respectively. According to Iranian procedure, the maximum tensile stresses is more than gravity stresses by 7% and about 3.7% for flat and camber jack arch slabs respectively.

In comparison the tensile stresses of vertical component and dead load combination obtained from both UBC code procedure (0.35 MPa and 0.32 MPa for flat and camber respectively) and Iranian code procedure (0.30 MPa and 0.28 MPa for flat and camber respectively), with experimental measurements of tensile bonding strength of 0.332 MPa and modulus of rupture of 0.327, its clearly that the Iranian procedure more realistic than UBC code procedure which gives more conservative results due to Iranian procedure take into account characteristics of jack arch slab like R-factor value, effect of steel beams on modulus of elasticity of masonry which is not accounted in UBC code.

In comparison stresses values with allowable stresses its clearly that only tensile stress is critical, in which in several cases the resulted stresses exceed allowable stress but still below tensile strength of masonry slab, therefore the tensile strength of the slab can be improved using wire mesh which cheap and easy improvement.

9.CONCLUSIONS

The following conclusions can be drawn from the present study:

1- The jack arch slab with camber not less than 2 cm has less deflection, higher ultimate load, less stresses than flat jack arch slab under both gravity and seismic loadings.

2- The vertical component of seismic loads is govern the design of jack arch slab southern Iraq, and the horizontal components of seismic forces have negligible effects on stresses, deflections and design of jack arch slab in comparison with gravity loadings.

3- For camber slab, tensile strength should be obtained by bond tensile strength, while in case of flat slab tensile strength could be obtained by tensile flexural strength similar to modulus of rupture of concrete.

4- The tensile strength of flat slab obtained by both bond tensile strength and flexural tensile strength is closed namely 0.332 MPa and 0.327 MPa respectively.

5- The Iranian procedure presented by **(Maheri and Rahmani, 2003)** is more reasonable than UBC procedure in calculation seismic loads on jack arch slab due to UBC not take into consideration this type of roofs and Iranian procedure present good and practical estimations for some parameters like R factor and participate of steel beams in slab stiffness so its recommended to use Iranian procedure presented in this study when deign jack arch slab to seismic loads southern Iraq.

6- The maximum tensile stresses for gravity loads are 0.28 and 0.27 and for seismic loads are 0.35 and 0.32, for both flat and camber slabs respectively, which is close to the allowable value of 0.33 MPa, thus the tensile strength of jack arch slab is critical under both gravity and seismic loads.

7- The maximum stresses and deflections of steel IPE beams obtained from finite element model are 69 MPa and 7.7 mm respectively, for commonly used 4m as a maximum span of steel IPE steel beams carried jack arch slab southern Iraq, these values are within allowable limits of140 MPa and 11.11 mm for stresses and deflections, respectively.

8- According to the experimental investigation of tested specimens, the failure of specimens were mainly due to bottom tensile stresses. Thus for traditional jack arch slabs in southern Iraq is either flat slab or with relatively small camber of 2 cm the brick arches behave as bending plate and the flexural failure is govern it is behavior.

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Table (1): Horizontal and vertical seismic loads based on UBC and Iranian procedure

Code	Load	W
Horizontal Load by UBC 1997 Procedure	0.225 W	1630.1.1: Only Dead Load
Vertical Load by UBC 1997 Procedure	0.3 W	
Vertical Load by Iranian Procedure	0.183We	2.3.1: Dead Load+20%Live Load

Table (2): Results of finite element investigations

Load Case	Direction	Load Comb.	Max. Slab Compressive stress, MPa		Max. Slab Tensile stress, MPa		Max. steel stress, MPa		Maximum IPE steel deflection, mm	
			Flat	Camber	Flat	Camber	Flat	Camber	Flat	Camber
1	Vertical	D+L	0.28	0.28	0.28	0.27	62	58.8	7.53	7.3
2	Horizontal	D+L+EX/1.4 UBC Code	0.29	0.29	0.29	0.27	62	59.2	7.53	7.4
3	Horizontal	D+L+EZ/1.4 UBC Code	0.3	0.29	0.27	0.25	62	58.7	7.53	7.3
4	Vertical	0.9D+EY/1.4 UBC Code	0.11	0.14	0.11	0.14	19	18.7	2.9	2.8
5	Vertical	0.9D-EY/1.4 UBC Code	**0.35**	**0.35**	**0.35**	**0.32**	**69**	**65.5**	**7.9**	**7.7**
6	Vertical	0.9D+EY/1.4 Iranian Code	0.14	0.14	0.14	0.15	27.7	26.5	3.7	3.6
7	Vertical	0.9D-EY/1.4 Iranian Code	0.3	0.3	0.3	0.28	62	57.7	7.03	6.9

Figure (1): Traditionally jack arch slab in south of Iraq

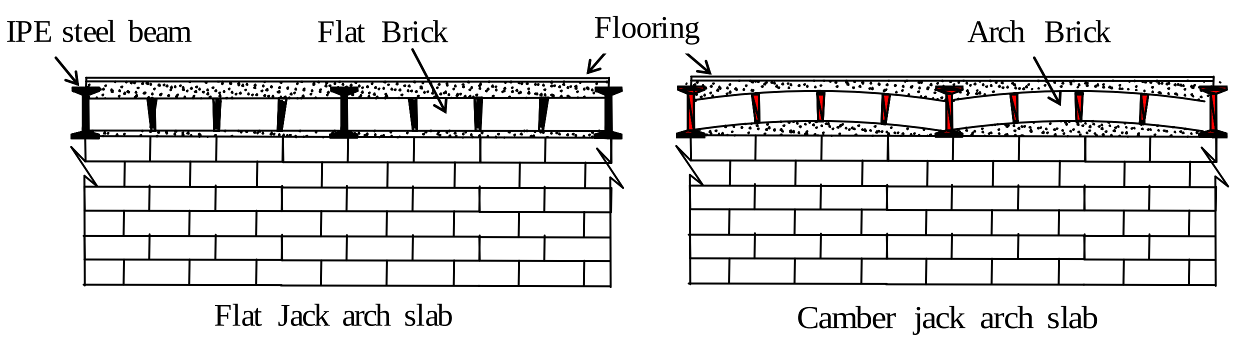


Figure (2): Construction details of traditional jack arch slab in Iraq

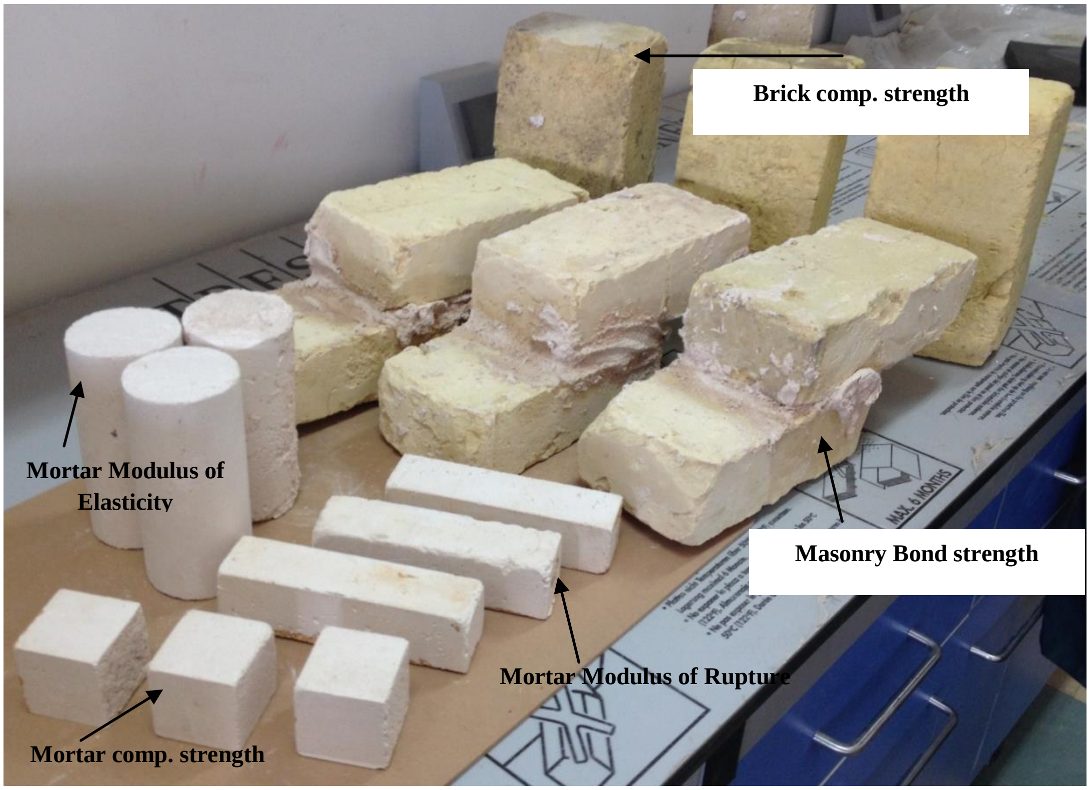


Figure (3): Brick and mortar specimens

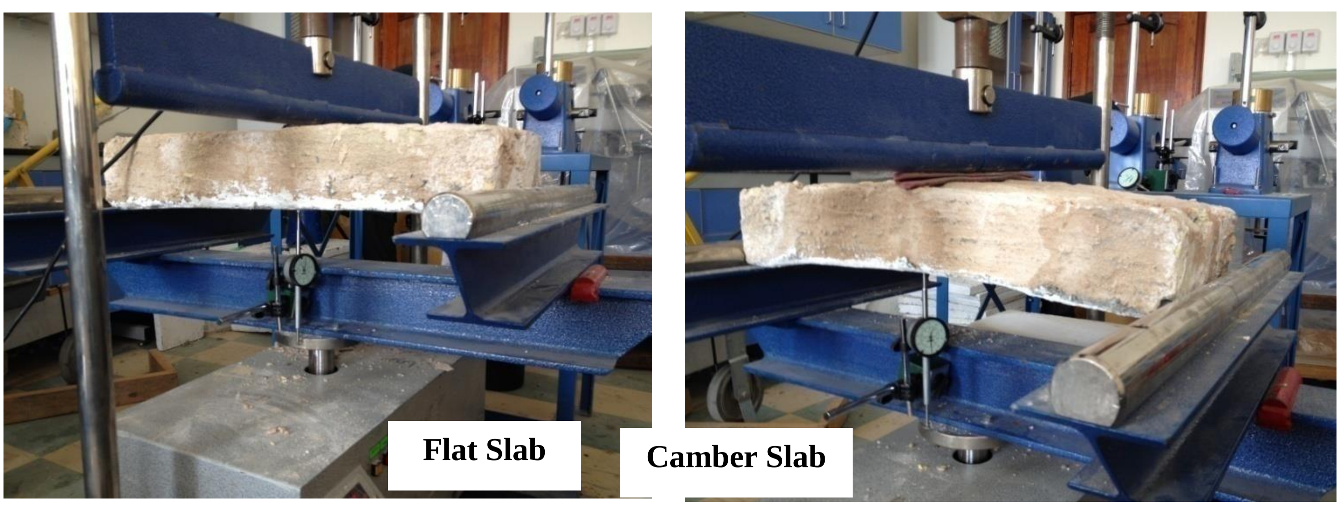


Figure (4): Flexural Tests of Jack arch slab specimens

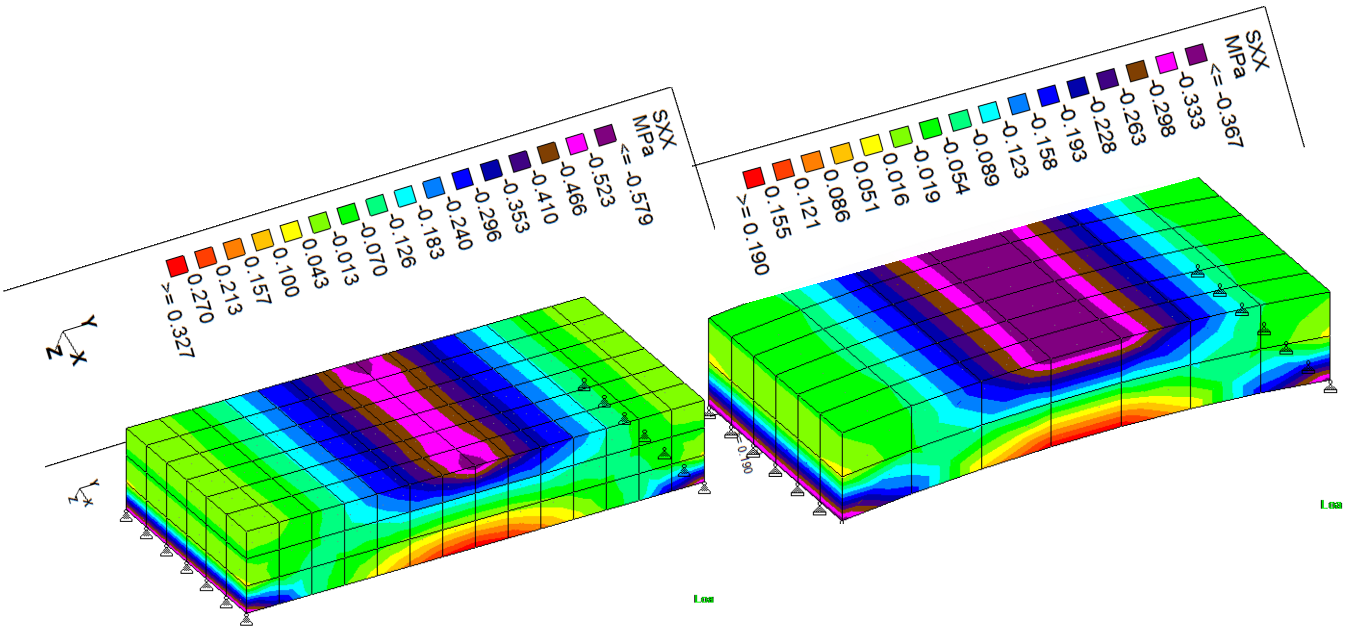
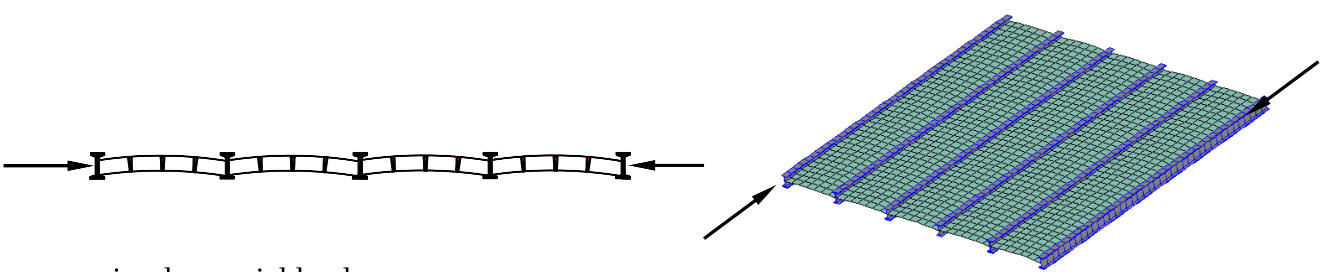


Figure (5): Three Dimensional Finite Element models for jack arch slab specimens



a- in-plane axial loads perpendicular to the steel beams

b- in-plane shear parallel to the steel beams

Figure (6): The earthquake-induced horizontal forces acting on the slab

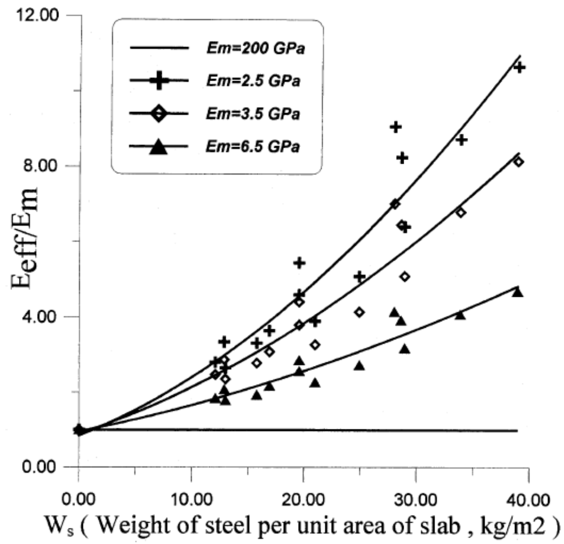


Figure (7): The effective modulus of elasticity (E_{eff}) of the jack arch slab, (Maheri and Rahmani, 2003)

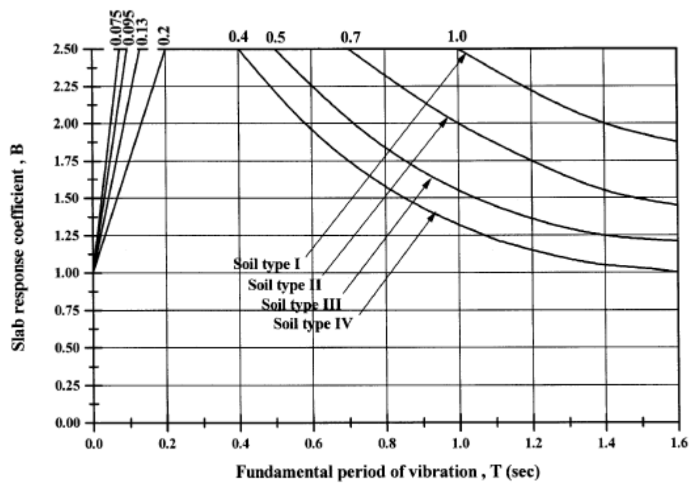


Figure (8): The proposed dynamic response coefficient B for jack arch slab, (Maheri and Rahmani, 2003)

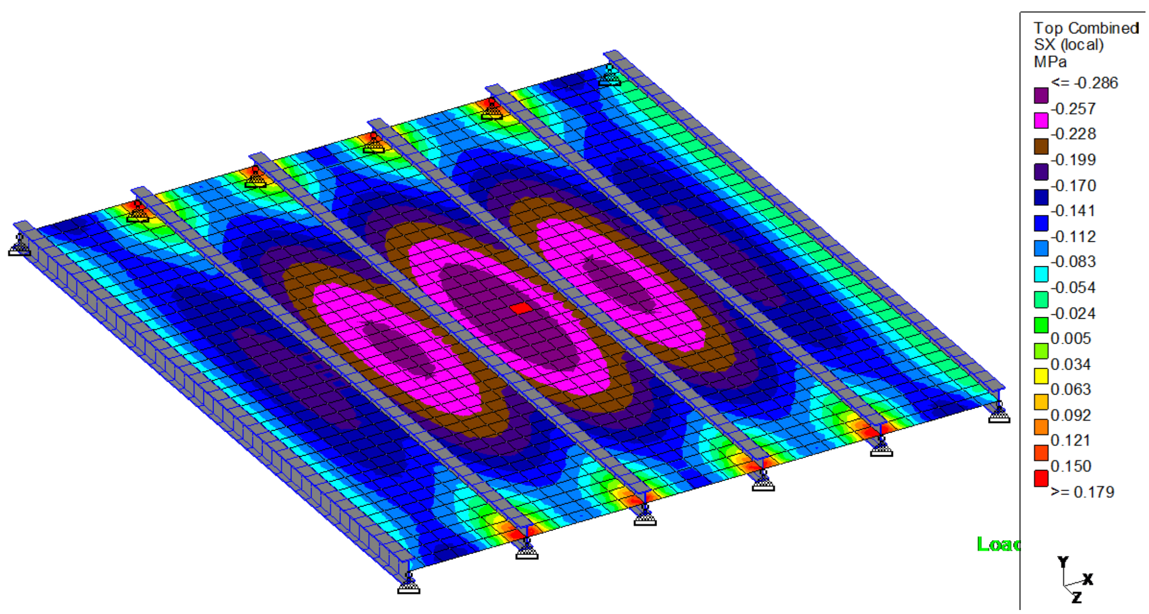


Figure (9): Typical stress contours of jack arch slab