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Behaviour of structural systems in residential buildings due to war damage caused by the Iraqi invasion

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ABSTRACT

The damage inflicted to buildings in Kuwait as a result of the Iraqi invasion and subsequent occupation before liberation required comprehensive assessment and evaluation of the safety for all supporting structural systems as a whole. Structural safety and cost dictated the feasibility of solutions which included repair, partial replacement, or complete demolition and rebuilding.

The present study is a report of buildings surveyed by the authors as requested by the governmental authorities. The performance of their structural systems was examined under such abnormal loading (fire and/or shelling) as was carried out. A detailed description of case studies representing the behaviour of each systern under fire and shelling is reported herein. Conclusions are made about the reliability of such structures and considerations for the construction industry.

Keywords: abnormal loading (fire and shelling); damage assessment; infill walls; RC frame structures.

INTRODUCTION

In August 1990 Iraq invaded its neighbor, Kuwait, and occupied the country for seven months until its liberation after the Gulf War. During this occupation, various buildings were subjected to shelling and/or fire. The extent of shelling and types of bombs used are difficult to document. In either case, considerable damage was done by both fire and shelling.

After liberation, the Kuwaiti government took on the responsibility of compensating the owners of these houses by either repairing or replacing them, depending on the extent of the damage. The authors of this paper were assigned to assess the extent of damage to these houses and recommend appropriate courses of action.

In this paper, an analysis of the performance of the different structural systems used in Kuwaiti residential buildings under such abnormal loading is carried out.

In addition, a detailed description and explanation of several case studies of different structural systems is reported herein. In addition, a statistical study was carried out to technically examine the impact of the war damage.

BUILDING SYSTEMS USED IN KUWAIT

Figure 1 summarizes the most widely used building systems in Kuwait. The predominant system is a reinforced concrete frame with infill concrete block walls and outside cladding, which may be stone or brick veneer. A detailed description of this system is given by Fereig and Horn (1990). The reason for such wide use of this system is the availability of materials such as sand, gravel and cement, and the availability of manpower with experience in such types of construction.

In the late 1940s and early 1950s, before the introduction of reinforced concrete, the most common building system in Kuwait was unreinforced load-bearing masonry walls with wood flooring. This system is still in use today, but on a limited scale, for construction of one and two-storey houses. The wood floors have been replaced by reinforced concrete slabs, while masonry walls have become high quality concrete blocks.

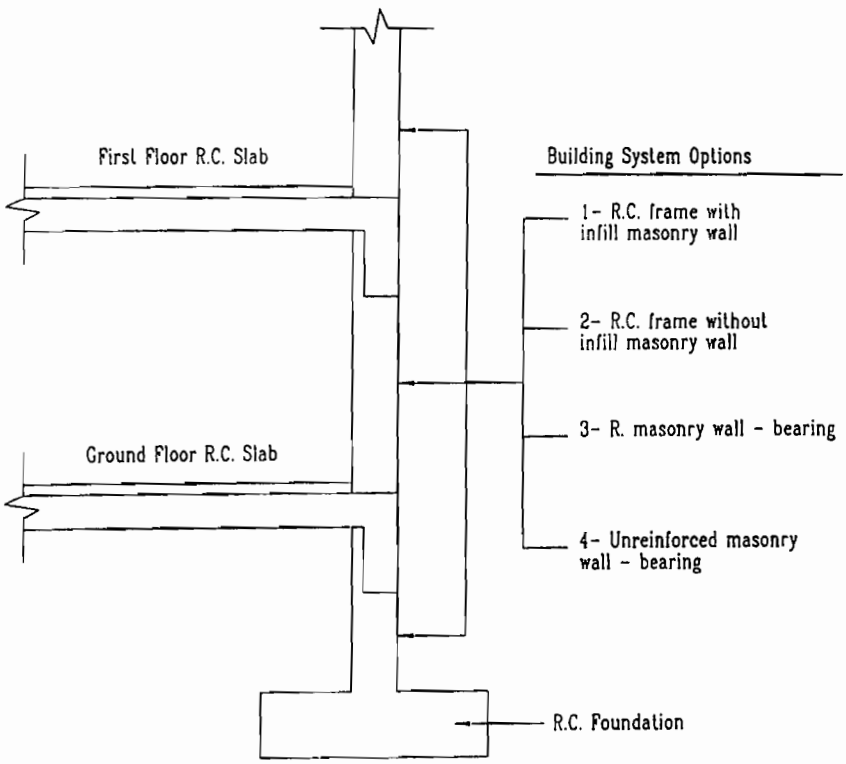

Fig. 1. The most widely used systems in Kuwait residential buildings.

In the early 1970's Kuwait witnessed a huge construction boom accompanying the oil boom. New systems emerged to compete with the existing concrete frame system, mainly unreinforced concrete masonry and reinforced concrete load-bearing wall systems. These two systems have been used in a number of projects built by the National Housing Authority, which is responsible for the construction of public housing projects. Neither the reinforced concrete load-bearing walls nor the unreinforced masonry load-bearing walls proved to be a viable alternative for the existing reinforced concrete frame system. Therefore, the reinforced concrete frame system remains the most widely used system (Al-Khaiat 1993).

The authors were asked to survey and assess a total of 50 damaged houses, out of which 43 had a reinforced concrete (RC) skeleton with infill walls, and two houses had an RC skeleton without infill walls. In addition, three houses were built using a combination of RC skeleton and load-bearing walls, while two were built using unreinforced masonry load-bearing walls. Some buildings had been subjected to both shelling and fire.

It should be mentioned here that steel structures are used in Kuwait for industrial buildings, stores, and shops. Several steel structures subjected to shelling and/or fire were also investigated by the authors. The recommendation was to completely demolish and rebuild because these structures were found to be severely damaged and beyond repair.

Comprehensive field surveys of damaged buildings were carried out. This included visual inspection, core testing, and review of structural drawings and specifications. A number of problems were encountered during the condition survey:

- Complete drawings, specifications, and design calculations were not always available.
- Discrepancies were found between as-designed and as-built construction details.
- In some cases, there was a limited reserve capacity of structural members, particularly columns.
- There was inadequate quality control during the construction phase as reflected by a large variability in strength from core tests.

STATISTICAL STUDY

The study to document the impact of the war damage on the buildings in Kuwait included the results of all 50 buildings investigated and assessed. The investigation also included the kind of structural system used and how it was affected by damage, the possibility of repair or replacement, and the age of the building. It is hoped that this study will help in comprehensively evaluating construction and will lead to recommendations that will help in setting up suitable plans for future construction in Kuwait.

Figure 2 shows the different kinds of building systems used in Kuwaiti residential buildings. It is clear that the predominant system is reinforced concrete frame with infill concrete block walls. It can be concluded from Fig. 3 that the observed damage including shelling, heavy fire or a combination of both, created abnormal loadings on the structures that may have caused the buildings to exceed their design loads. The predominant damage was shelling, found in approximately 55% of the cases studied.

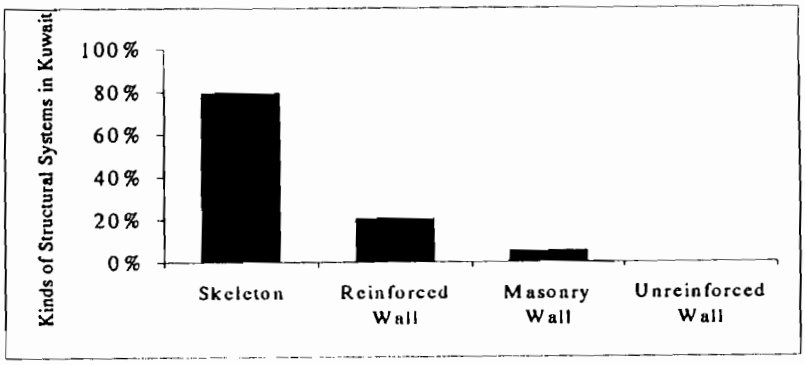

Fig. 2. Distribution of different structural systems in Kuwait.

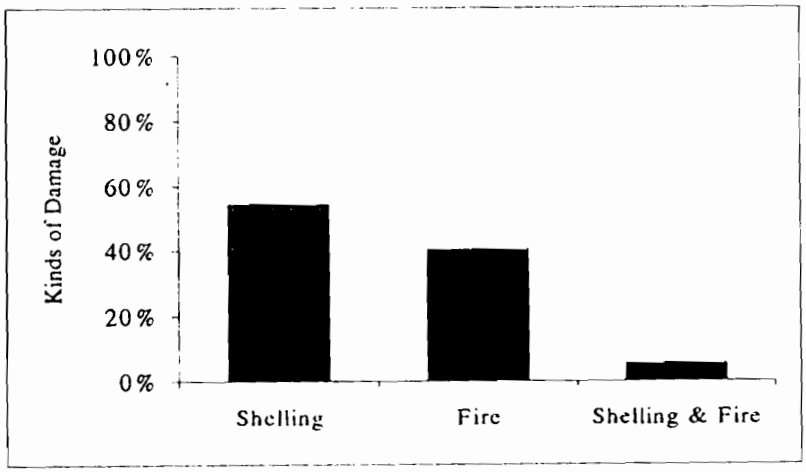

Fig. 3. Distribution of buildings subjected to shelling and/or fire for the 50 buildings surveyed.

Damage ranged from minor spalling to complete failure of the structural elements. Repair or replacement was implemented to restore the strength and durability of the damaged or failed elements. About 60% of the damaged buildings were repaired and reused, as shown in Fig. 4.

The most damage was concentrated in reinforced concrete frame systems (from either shelling or fire) because this system had been widely used, as shown in Fig. 5. It is clear from Fig. 6 that most repair work was carried out on buildings which had suffered fire damage. No building was demolished due to fire even if it had been exposed to heavy fire. Most of the demolished buildings had been subjected to

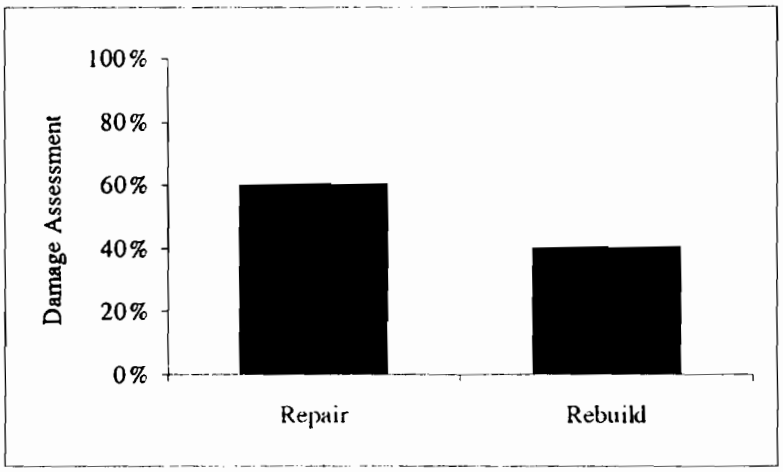

Fig. 4. Distribution of repaired and rebuilt buildings for the 50 buildings surveyed.

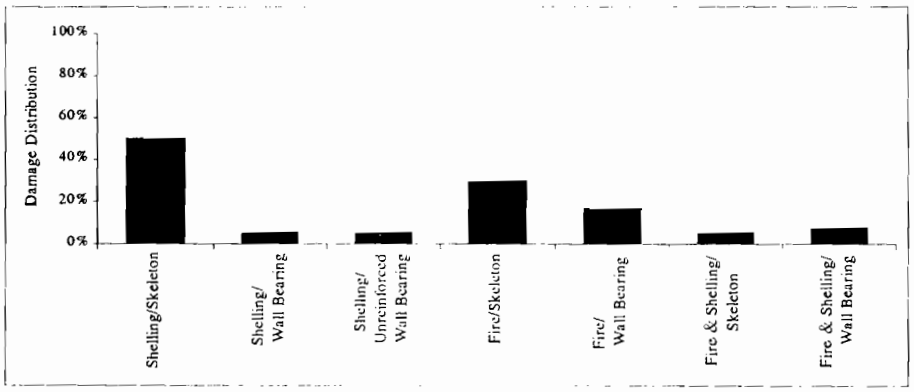

Fig. 5. Distribution of the 50 buildings surveyed according to structural system and effect of damage.

shelling. The study indicates that about 50% of the damaged buildings were 20 to 30 years old. In addition, about 40% of the repaired buildings were repaired and reused, as shown in Fig. 7.

BEHAVIOUR OF STRUCTURAL SYSTEMS DUE TO WAR DAMAGES

The response of each system under such abnormal conditions was different. In the following sections, a detailed description and explanation is given for several case studies representing the performance of each system under fire and shelling.

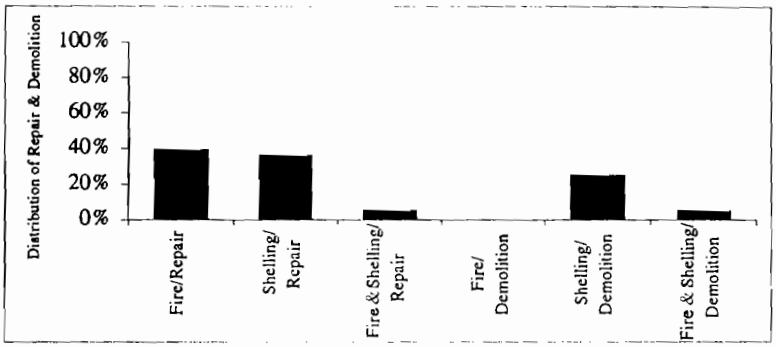

Fig. 6. Distribution of the 50 buildings surveyed according to effect of damage and the condition of repair or demolish.

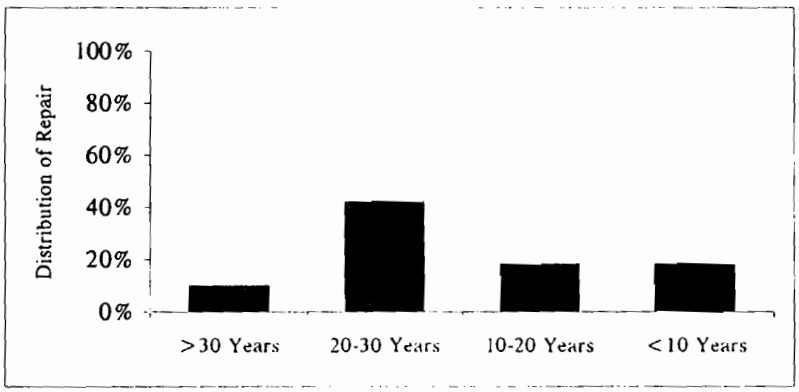

Fig. 7. Distribution of the 50 buildings surveyed according to their age.

RC skeleton and infill walls

Under fire

Several houses with RC skeleton and infill walls subjected to fire were investigated. Some cases had had localized fire of short duration which did not affect the structural integrity of the building. Repair of the non-structural elements was recommended. However, some buildings were subjected to fire and severely damaged. It was found that the damage done by fire was very limited and localized due to the presence of the infill walls. Severe damage in the structural elements was found, from the concrete deterioration, to be due to the old age of the building, and also from neglected maintenance. It was recommended in these cases to partially replace or completely demolish the building according to the estimated cost and the extent of the damage. In the following section, a brief description of one of the investigated houses is reported.

A two-storey villa in the Jabriya area of Kuwait City was set on fire. The outside walls were made of 200 mm concrete hollow blocks, with ceramic tiles as exterior cladding. The inner partitions were of 100 mm width concrete blocks, and both the internal and external walls were covered with 20 mm cement mortar. Unfortunately, there was no documentation as to the duration of the fire, nor the temperature reached during the fire. However, the fire was extensive. A thorough investigation of the building was carried out using non-destructive testing, and cores were taken from the main structural elements all of which led to the conclusion that this building was still structurally sound and could be reused.

Due to the presence of the masonry elements and their resistance to fire, the fire damage was contained within the specific rooms in which incendiary bombs were placed. Thus the masonry elements acted as a buffer to prevent the fire from spreading. Also, the plaster acted as a fire coat to limit the fire damage to the structural elements. Due to the intense heat, the bond between the glazed tiles used as an external veneer disintegrated and was lost.

Under shelling

Several houses with RC skeleton infilled with walls and subjected to direct shelling were investigated. Some of them were only locally damaged due to shelling and the remaining part of the building was found to be in good condition with no indication of excessive stress in the structural elements observed. The recommendation in these cases was repair of the damaged elements and reuse of the building. However, some houses subjected to direct shelling were severely damaged, and the structural elements capacity was affected. In other cases, in addition to the effect of shelling, the compressive strength of the structural elements was found to be very low due to aging. In these cases, it was recommended to partially replace or completely demolish according to the repair cost and the extent of the damage. In the following section, a brief description of two case studies representing the response of this structural system under direct shelling is given.

The case study presented is of a two-storey house in Al-Jahra, in the north of Kuwait City. The building was 20 m long and 20 m wide and was five years old. The outside walls were made of 200 mm concrete blocks with 50 mm of sand-lime bricks as exterior cladding. The inner partitions were of 100 mm width concrete block, and the internal and external walls were covered with 20 mm of cement mortar.

The building was subjected to direct shelling from above which passed through the roof slab of the building and through a joint of column and beams at the first floor level, causing the removal of the joint. Major cracks appeared in the walls. No cracks or buckling were noticed in the columns or beams adjacent to the collapsed ones. A condition survey was carried out to evaluate the different structural elements of the building. The test results led to the conclusion that this building was still structurally sound and could be repaired and reused, especially since the damage was very limited and localized. Repair work including reconstruction of the collapsed beams and columns composing the damaged joint was carried out, followed by reconstruction of the slabs damaged by shelling.

Another case study of an RC skeleton house subjected to direct shelling in Al-Sulibikhat was recorded. The building was about 20 years old. The direct shelling led to a complete collapse of the roof slab and, accordingly, many slabs, beams and

columns of the building were damaged. Due to the severe damage and the age of the building, repair work was found to be useless and demolition of the house was recommended.

Under fire and shelling

The case study selected here was a two-storey house in the Al-Ferdous area of Kuwait City. The building was subjected to fire and direct shelling during the Gulf War. Three main beams were damaged on the first floor and the joint between the column and these beams was removed. Due to fire, the plaster and the artificial ceiling were damaged. Because of the presence of the infill walls, however, the fire was limited to only two rooms.

Repair work, including reconstruction of the damaged beams and column and reconstruction of the damaged non-structural elements, was carried out and thus the building was reused.

RC skeleton without infill walls

Under fire

The case study presented here was of a multistorey commercial building having two underground levels for parking, two levels for shopping, two levels for more parking, and one top storey for residences. The complex was 137 m long and 75 m wide. The structural system was prestressed concrete slab and I-beams supported on cast-in-place post-tensioned prestressed concrete girders and cast-in-place reinforced concrete columns. Reinforced concrete walls were used for staircase shafts and for parking ramps.

Exposure to high temperatures for a long time resulted in heavy damage in the form of cracking and spalling of concrete, and large extension deformation of the reinforcing steel which resulted in large lateral expansion and spalling of the concrete cover. Due to a lack of adequate anchorage and spacing of lateral ties, longitudinal steel buckled after spalling of the cover resulting in a complete failure of the column. Some slabs experienced yielding of the main steel and there was subsequent excessive deflection and sagging. Vertical cracks 0.3 to 0.50 mm wide at nearly equal spacing of roughly 0.20 m were observed in the prestressed beams. It seemed that the prestressing wires experienced a significant loss of prestressing, which resulted in the observed vertical flexural cracks.

Concrete cores were drilled from slabs, beams and columns and tested under axial compression to determine the residual compressive strength of the concrete. The residual mean compressive strengths of concrete cores taken from slabs, beams and columns were 14, 14.7 and 15.3 MPa, respectively. Comparing these values with the design compressive strength indicates a reduction in strength of 40, 37 and 47 percent for slabs, beams and columns, respectively. This indicated a significant reduction in compressive strength, which was mainly attributed to exposure to high temperature from fire and subsequent cooling.

Structural analysis of selected key elements was performed using the material properties determined from the core tests. The analysis revealed that many slabs had reached their capacity under service loads due to the reduction in strength

of concrete and steel under high temperature during fire. The analysis also showed that some columns had been under-designed and consequently did not have an adequate margin of safety.

Precast slabs that were exposed to heavy fire suffered excessive deflection and sagging beyond repair. These slabs were removed and replaced by other cast-in-place slabs. Most of the defective columns were damaged beyond repair. The solution was to probe the structure, remove these columns and replace them with steel columns. The base plates of the steel columns were fixed to the floor beams. To avoid any overload to the beams, steel columns were installed at all levels below the level containing the damaged columns.

Under shelling

Al-Zoor Pumping Station was chosen to represent the case of damage by shelling in RC structures without infill walls (Al-Khaiat 1999). The building consisted of one level that was 30 m in length, 27 m in width and 6 m in height. During the Gulf War, a blast occurred near a corner column of the building resulting in severe damage in the immediate vicinity and causing the column and attached beams to collapse. It also caused cracking in the adjacent beams, slabs and columns.

The severity of such cracking differed from one location to another. In total, four columns, five beams and three slabs collapsed and were removed. To assess the damage in the remaining parts of the building, a condition survey was carried out on the structural elements. The results show that the condition of the existing concrete and reinforcing steel was acceptable.

Some of the damaged slabs were found to be beyond repair and had to be replaced. The beams with only minor cracks affecting the structural capacity had to be strengthened with steel beam C-shapes at the bottom. Some beams were also found to be beyond repair and had to be replaced with new concrete, utilizing the existing reinforcement. The columns which had minor cracks affecting the structural capacity were strengthened using four steel angles at the corner of the column.

After repair work was carried out, a load test was performed to ensure the restoration of the structural capacity of the building.

RC skeleton and load-bearing walls

Under fire

This case study is of a two-storey house in the Sabah Al-Salem area of Kuwait City. The house was about 12 years old and had been subjected to fire during the Gulf War. The damage was limited to only three rooms, one on each floor. It was concluded from visual inspection and core tests that the fire had not been severe and had not affected the capacity of the structural elements. The concrete slab of the third room on the second floor was found to have very low compressive strength and this was attributed to the poor quality of concrete in this slab.

In general, the building was found to be structurally sound and was reused after replacing the deteriorated concrete slab and repairing the non-structural elements.

Under shelling
The only case study found in this system is a two-storey house in the Al-Fahaheel area of Kuwait City. The age of the building was about 20 years; it had been subjected to direct shelling near the fence of the building and the concrete slabs and walls adjacent to the fence were damaged. The rest of the building was found to be in good condition and no cracks or excessive deflections were observed in any other structural elements. After repair of the damaged elements, the building was reused.

Under fire and shelling
A two-storey house in the Rumaithiyah area was the only case study for this system. The building was about 17 years old. Its structural system was a combination of RC skeleton and RC load-bearing walls. The building was subjected to fire and direct shelling. The fire was limited to one room on the ground floor, but the smoke covered the first floor walls and slabs. It was observed that there were no cracks or excessive deflections in the structural elements of the building. The core tests drilled from slabs and walls indicated that the residual compressive strength of concrete in slabs was fairly good, while it was very low for the RC walls. Structural analysis of the capacity of these RC walls was performed and it was concluded that these walls were able to carry the applied loads safely. The building was reused after repair of the non-structural elements.

Unreinforced masonry load-bearing walls

Under fire
The case study was a two-storey house in the Al-Ferdous area of Kuwait City. The structural system was unreinforced masonry load-bearing walls and reinforced concrete slabs. The building was subjected to fire in one room on the ground floor and most of the first floor rooms. The walls lost their plaster and the concrete slabs lost their reinforcing steel cover. It was observed that there were no cracks or excessive deflections in the walls or slabs indicating that the damage was very limited and local. The building was reused after the repair work was done.

Under shelling
A two-storey building of about 20 years old in the Al-Omaryiah area of Kuwait City was the case study of load-bearing walls under direct shelling. One masonry wall and three concrete slabs were affected by the direct shelling of the building, and holes of about 1.0 m diameter were found in these elements. The remaining part of the building was found to be in good condition and no evidence of collapse was found in the main structural elements. The building was reused after repair of the damaged elements.

SUMMARY AND CONCLUSIONS

The damage that occurred to buildings in Kuwait as a result of the Gulf War created abnormal loading (fire and shelling) on the structures that may have caused them to exceed their design loads. The damage ranged from minor cracking and spalling to complete failure. An analysis of the performance of the different building systems

used in Kuwait under such abnormal loading was carried out in this paper. A detailed description of case studies representing the behaviour of each system under fire and shelling was reported herein. The main conclusions drawn from this study are as follows:

1. Each structural system under such abnormal loading behaved differently. The most damage was concentrated in RC skeleton systems as this system is widely used in Kuwait.
2. The normal practices in construction of Kuwaiti houses is to use masonry walls (either infill or load bearing). Such practices proved to be very useful under these circumstances, because they achieved the following two main functions:
   i. Due to their higher resistance to fire, they prevented fire from spreading to adjacent rooms.
   ii. In the case of infill walls, after the loss of supporting members, these walls acted as load-bearing elements and kept the building standing, thus saving lives and enabling repair work to be carried out later.
3. The most predominant repair was for fire damage and no case structure has been demolished, even if the building was exposed to extensive fire. Most of the demolished buildings had been exposed to shelling.
4. The prestressed concrete structural systems were found to be significantly affected by fire, especially in the case of extensive fire where the prestressing force may have been lost.
5. During the field survey, it was observed that the higher percentage of damaged buildings were 20 to 30 years old. Although the age of these buildings exceeded 20 years, they underwent the repair process. The good construction of these buildings made them capable of withstanding severe war damage.

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دراسة حول تصرفات الأنظمة الإنشائية في المباني السكنية التي تعرضت للدمار نتيجة للغزو العراقي الغاشم

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خلاصة

تعرض هذه الورقة دراسة شاملة حول تقييم الأضرار ، ومدى سلامة الأنظمة الإنشائية ككل للمباني التي تعرضت للدمار نتيجة للغزو العراقي الغاشم لدولة الكويت وما تبعه من احتلال حتى التحرير.

مدى سلامة هذه الأنظمة وتكلفة إصلاحها إذا وجدت هي العامل الأساسي لتقرير الجدوى من الإصلاح أو الإزالة أو الإبقاء عليها. حيث اشتملت الحلول الإصلاح أو الإبدال الجزئي أو الإزالة وإعادة البناء.

قام المؤلفون بمسح ميداني لمجموعة المباني المتضررة بطلب من الجهات الحكومية لأغراض تقدير الأضرار التي أصابت هذه المباني نتيجة للوضع غير العادي.

تفاصيل حول جميع الحالات المدونة كل حسب النظام الإنشائي الذي يكون عناصره ونوع الضرر الذي تعرض له شملتها الدراسة وإمكانية الاستفادة من هذه النتائج في الصناعة الإنشائية.