



Evaluation of Reuse of Demolition and Construction Waste in Geotechnical Engineering Works with A Case Study: Mosul City (Review)

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ABSTRACT

Demolition and construction waste are among the topics that focus by many researchers. The methods of reuse of waste materials must reduce the economic and environmental pressure of their presence in various regions. Before 2014, the city of Mosul contained relatively small quantities of demolition and construction debris, especially concrete rubble, asphalt materials, and bricks (they formed approximately 80% of the construction and demolition debris). These materials increased very greatly after the liberation operations and the widespread destruction of large parts of the city and became a great problem in the reconstruction operations. There is no clear plan yet in the city to deal with this debris, and it is disposed of by moving them to another place or burying them randomly when rebuilding the destroyed parts. This study shows to deal with demolition and construction debris in Mosul after liberation and during reconstruction operations. Also, many sources and data dealing with the re-use of demolition and construction debris in the field of geotechnical engineering for operations to improve the engineering properties of soils are presented. Many papers show the possibility of using construction and demolition waste as an alternative base or sub-base materials, fill for embankments, or increase durability and reduce the swelling and plasticity of clay. The study concludes that the researches and data can be used to deal with the rubble of demolition and construction in Mosul in a way that enables to benefit from it economically and environmentally.

1. Introduction

Waste resulting from the construction, redesign, and restoration of homes, commercial buildings, and other civil engineering activities is classified as construction waste. Whereas, waste resulting from building demolition and demolition operations is classified as demolition waste [1-6]. Demolition waste is also produced from environmental disasters such as earthquakes, hurricanes, floods, and wars [6,7]. In recent decades, demolition and construction waste has become one of the topics that attract the attention and interest of researchers and environmental reports. According to a study conducted by [8], the construction sector

consumes around half of the raw materials in nature and produces more than half of the overall waste in the world. demolition and construction waste are defined as solid waste produced from construction and demolition activities, as shown in Table 1[9]. Most of the materials referred to in the table such as crushed concrete, asphalt rubble, plastic, etc. Steel, wood, and others cause economic and environmental problems when accumulated. The problem of construction and demolition waste is growing rapidly in developing countries, including Iraq. Few previous studies dealt with construction and demolition waste in Iraq [10-14], and some studies have shown that there is no system for waste management in

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construction projects in Iraq [15]. Demolition and construction debris constitute about half of the solid waste in the world, and of this half, concrete rubble constitutes about 58%, brick rubble about 16%, and asphalt pavement rubble constitutes about 7% [16]. Because these materials constitute about 80% of the demolition

debris and construction and due to the abundance of these materials in Mosul at present, these materials were chosen in this review. The study shows the researches that focused on reusing the waste for engineering purposes, especially in the field of geotechnical engineering.

Table 1: Types of construction and sources of demolition waste [9]

The sources of waste production	Type of waste
streets, roads, bridges, parking lots	Asphalt
dust, dirt, bricks, brick ash, and concrete	Breaker
gypsum board, gypsum walls	Plaster
doors, windows	Glass
doors, windows, all forms of plastic sections	Plastic
bituminous insulation sheets, mastic	Waterproofing materials (bituminous products)
pipes, steel roofs, steel sections	Iron waste
Non-ferrous metals aluminum, copper, and steel	Non-ferrous metals
products, decorations, wooden sections, and furniture	Natural wood
Plywood, pressure treated, creosote-treated, laminates	Treated wood
lead-based paint, fiberglass, asbestos, fuel tanks	Contaminant

Mosul is one of the historical cities located in northern Iraq on the banks of the Tigris River, and it is located on rock layers consisting of gypsum rocks, anhydrite, and lime [17]. The residents of the city benefited from the natural resources available in the vicinity of the city for construction. Among these materials were limestone, gypsum stone, and clay. The building materials, used in the construction of the old city through previous eras, were manufactured locally such as plaster, pottery, and bricks [18]. As a result of the development in construction, materials of concrete, iron, tiles, asphalt, plastic, glass, and bricks entered into modern construction since the middle of the twentieth century and were used to build different houses and facilities all over Mosul. The quantities of construction and demolition waste before the recent war in the city of Mosul were not at the size that causes major problems, because of the

presence of large areas where waste is dumped randomly most of the time. Also, the nature of the activities associated with the production of these wastes in Mosul was not at the level of the cause of great economic or environmental stress. For example, the demolition of large or multi-story structures was very rare in Mosul in the pre-war stage due to the weak commercial and service reality and the modernity of most of the buildings. After the last war, the problem of construction and demolition waste appeared in a big way due to the huge scale of destruction. According to United Nations estimates [19], piles of rubble were more than 10 million tons, as shown in Figure (1). This rubble was concentrated in the old city, which is the center of the city of Mosul, as shown in Figure (2).

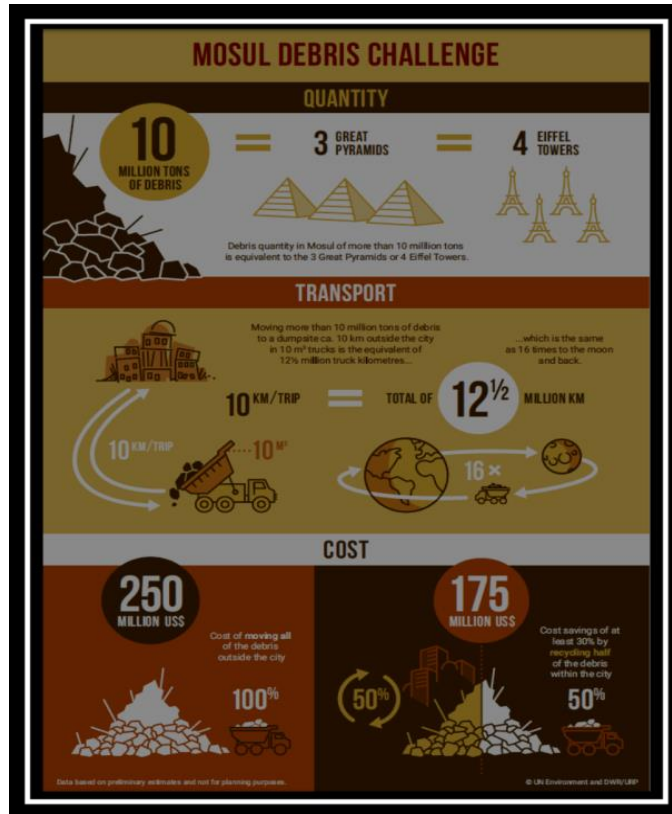


Figure1. Rubble left behind in Mosul after the war with the challenges of dealing with it

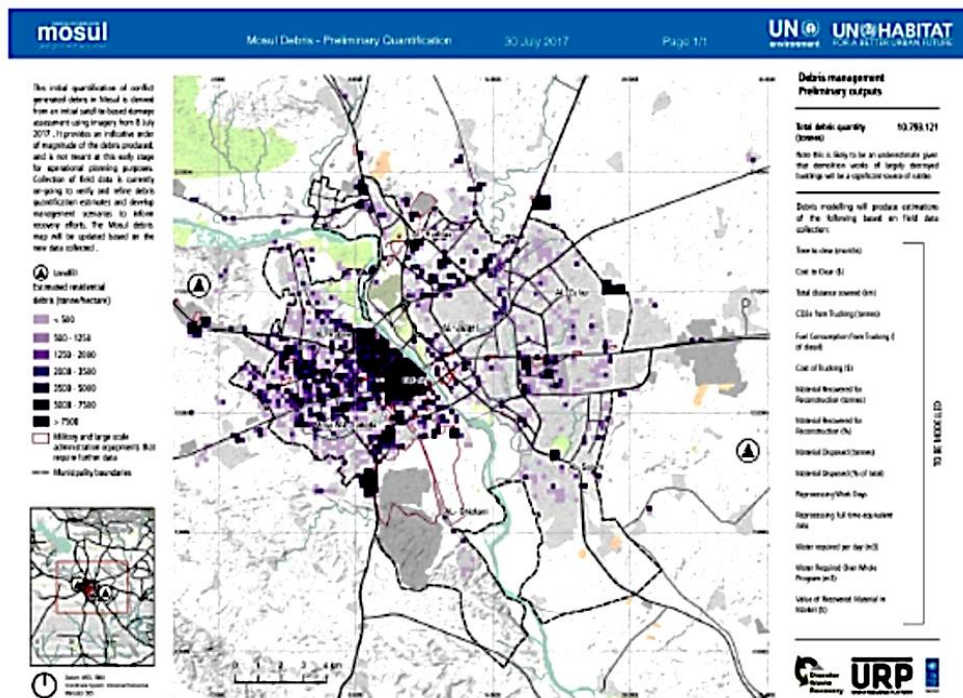


Figure 2. Concentration of remnants and debris of the last war in Mosul, according to United Nations statistics[19]

2. Waste concrete materials in Mosul

Concrete is considered one of the most important materials used in construction in the modern era due to its abundance and high resistance in construction and weather conditions, and the abundance of its raw materials (cement, sand, and gravel). Concrete is a mixture or combination of several components that are joined together, containing fine cement, water, and sand, small crushed stones (aggregates), and natural gravel added to it. Concrete is considered one of the components of modern construction and enters in large parts of it. The concrete materials are divided into two types: plain concrete, which is used in many parts of small establishments such as housing and commercial and industrial buildings. Plain concrete is used in the manufacture of various building units such as building blocks (blocks), cache, and floor casting, and it is used to fill some voids in the building. The other type, which is the reinforced concrete, which reinforcing iron is added, increases its durability and strength and remains for some time without being affected or corroded. Reinforced concrete is generally used in foundations, columns, roofs, etc. Concrete waste is found in Mosul in abundance, especially after the recent war, as a result of blasting and explosion operations. Concrete waste is found in abundance in the

bombed areas in most neighborhoods of Mosul, such as the old city, which contains large masses of concrete rubble (Figure 3A and B). With the continuing construction and reconstruction processes in Mosul, there is still no real benefit from concrete waste and its recycling, as this waste is thrown into open areas and the pits are filled in more randomly. A large part of concrete waste was thrown at the edge of the Tigris River and some of the pits were filled in and the remaining waste was collected in the form of piles in the same old city. As for the rest of the neighborhoods on the right side of Mosul, part of the concrete rubble was thrown in the polluted area on the right side of the city, and the other part of the rubble was dumped in large pits. As for the neighborhoods of the left side of the city of Mosul, part of the concrete rubble was thrown in open areas north and south of the left coast of Mosul. The other part of the concrete rubble was covered by sub-base materials near Al-Shamsiyat Village and Al-Qawsiyat District. The concrete waste resulting from the demolition of the building of the Electrical Engineering Department inside the University of Mosul was used on the road of Talekif and the other part was used to backfill and covers the sides of the trench that passes inside the university, and thus these wastes were disposed of as in Figure (4).



Figure 3. The rubble of concrete dumped in separate places in Mosul



Figure 4. The process of cladding the sides of the trocar near the publishing house inside the university

Many studies have been conducted on the reuse of concrete residues for engineering purposes, especially civil engineering works [20-23]. a field study was conducted to investigate the performance of pavement composed of concrete, asphalt mix, and ceramic waste aggregate [24]. The study analyzed the performance of a road surface course based on the values gained for the following variables: dry density, moisture, and deflections. The values obtained for a conventional road surface with a sub-base of quarry (natural) aggregate were compared to the values obtained for a road surface composed of recycled aggregate. It was detected that the load-bearing capacity of the recycled artificial CDW aggregate was acceptable and performs as well as natural quarry aggregate with some conditions. The study establishes that recycled aggregate made of concrete, ceramic material, and asphalt also had a lower density than natural aggregate. the use of ceramic tile rubble as a primary material was evaluated in road paving design [25]. The researchers explained that instead of disposing of it in landfills, ceramic tile waste could be used in highway engineering applications, and thus reducing its potential impact on the environment. The test results showed that adding waste ceramic tile residues increases the CBR value of the soil. The researchers also suggested the possibility of using ceramic waste

as an additive to improve the performance of CL-type clay soils in an economically and environmentally beneficial manner. Other researchers also demonstrated the possibility of using crushed concrete residues to improve the properties of organic soils by increasing the resistance and reducing plasticity and swelling [26]. A review was done to explore the possibility of using recycled aggregates arising from construction and demolition waste in new construction applications for many centuries [27]. The study summarizes the results in a table with the use of recycled concrete aggregate and other construction and demolition materials in civil engineering works. Lastly, a published paper demonstrates the geotechnical properties of recycled construction and demolition materials for filling applications [28]. The researchers used recycled construction and demolition materials as an alternative to virgin aggregates in geotechnical applications such as the filling works. The result of this study showed that construction and demolition materials can be a suitable alternative to virgin aggregate used in the filling.

3. Waste asphalt materials in Mosul

Asphalt is used a lot in paving streets, especially streets inside the city, and it has a lot of waste after street breaking and restoration. Asphalt consists of several chemicals, the

largest percentage of asphalt components is the carbon percentage, which occupies about (70-85) %, followed by hydrogen (7-12) %, then sulfur (1- 7%), then oxygen (0-5) %, and finally nitrogen occupies a ratio of (0-1) %. The asphalt mixture consists of three main layers, which are the base layer, the bond layer, and the surface layer. The base layer is made of regular or crushed gravel, sand, filler, and bitumen material. As for the second layer, it consists of crushed gravel at least by 90%, with sand used from the by-product of crushing the gravel as desirable. This mixture is used to obtain high stability. The thickness ranges from 5 cm to 8 cm, the surface layer has the same components as the second layer with different sizes, and its thickness ranges between 6 cm and 8 cm.

There was a small amount of waste asphalt materials in Mosul before the war due to the scarcity and intermittency of maintenance work. After the war, because of the widespread destruction of most streets, neighborhoods, and alleys, large quantities of asphalt waste were produced. Some of the waste asphalt materials were dumped on the shoulders of the roads, part of it was filled in pits, part of it was thrown in industrial areas, and the polluted area is on the left side of Mosul. While on the right side, a large part of it was filled in potholes because of the bombing, and the other part of it was dumped on the sides of the streets. Generally, most of the asphalt waste was thrown and collected near its places of presence due to the lack of maintenance work on the streets. Figure 5.



Figure 5. The asphalt materials rubble dumped in separate places in Mosul

Many evaluations and laboratory studies of the geotechnical, geological, and environmental properties of the solid wastes resulting from breaking and uprooting old or worn-out streets and roads have been carried out in previous studies. the potential reuse of used asphalt paving slag for full recycling and direct use was Investigated by [29]. The tests used to study the effect of used asphalt paving on the mechanical characteristics of recycled base materials taken from northern Utah in America were the free-tip oscillating shaft test to measure the stiffness and the CBR test for strength measurement. The results suggest in general, that the use of as

much RAP as possible is appropriate to reduce pavement reconstruction budgets and demonstrate environmental responsibility.

In a different study, a comprehensive experimental program to test two recycled materials, one of which used asphalt paving aggregates, as paving materials [30]. Experimental test results, along with field and field monitoring data, showed that this recycled material was suitable to use as a base material for the underlayment of roadbeds. The evaluation of reusing of reclaimed asphalt panels in road construction was shown in a study [31]. It concluded that reclaimed asphalt panels

were not suitable as a base material in high-load main roads, while they could be used as base material under paving for secondary roads. The laboratory evaluations of the use of reclaimed asphalt paving mixtures treated with cement and alkali-resistant glass fibers as base materials for underway paving were taken in the study [32]. A mixture containing asphalt aggregate was used and treated with Portland cement and alkali-resistant glass fibers in various quantities in a comprehensive laboratory test program. Tests include conductivity; leachate, unconfined compression, and small-strain shear moduli through resonant column testing. Leachate tests include pH, total and volatile dissolved solids, total and volatile suspended solids, and turbidity. The test results confirm the possibility of cement-fiber-treated RAP material as an environmentally and structurally comprehensive alternative to non-bonded materials for base and subbase applications in pavement engineering. An experimental study on the use of building waste destroyed by the earthquake in the form of recycled aggregate in asphalt mixtures was considered by researchers [33]. The waste materials were treated in recycled aggregates and used in asphalt mixtures with natural limestone aggregates. Liquid silicone resin was used for the pretreatment of recycled aggregates due to the high absorption and low strength of the recycled aggregates. Various tests were performed, including physical properties tests, surface properties tests for each of the recycled aggregates before treatment, moisture susceptibility test, triple bending test, and permanent deformation tests for asphalt mixtures. The paper results established that recycled aggregate mixtures without treatment are not suitable for use in asphalt mixtures due to their high absorption capacity. However, pretreatment of recycled coarse aggregate with the used liquid silicone resin improves the absorbency, strength, adhesion to asphalt, and surface tension of the recycled coarse aggregate. A study presented the feasibility of using waste asphalt pieces as paving and under-paving materials for roads [34]. The results showed that the use of waste asphalt pieces as paving and under-paving materials for roads is possible and

has been used by some transport agencies. The results also revealed that there are potential significant economic advantages if the asphalt cuttings used can be used as paving and under-paving materials for roads. Nearly 30% of material costs can be saved with a 50/50 combination of used asphalt waste and natural aggregates. A comprehensive review of several experimental studies on the use of asphalt cutter paving was presented [35]. The used treatment was a mixture of natural aggregate with pieces of used asphalt, cement, and a mixture of used asphalt pieces with lime. The authors discussed the main results of these studies, including the ratio of used asphalt to natural aggregate. Also, the study discussed in this review is the percentage of stabilizing factor, modulus, strength, and creep deformation of used asphalt cuttings treated under static loading, and permanent deformation of the used asphalt cuttings treated under cyclic loading. Lastly, the importance of RAP amount on the resilient modulus behavior, shear strength, and hydraulic conductivity characteristics of unbound granular base materials were discussed in a paper [36]. The standard tests include modified compaction, California Bearing Ratio (CBR), conductivity, and repeated and static triaxial. While, the microstructure tests include, the X-ray computed tomography (CT) scanning technique. According to tests results, the authors have demonstrated that mixing RAP with virgin aggregate produces superior quality material for road bases application.

4. Rubbles of clay bricks in Mosul

Bricks are known building units made of different materials used in the construction of houses and shops with heat, humidity, and sound insulation. Bricks consist of several types, including clay bricks, concrete bricks, regular fired bricks, glass bricks, and refractory bricks. In the past, clay bricks are made of clay and hay (straw) and are placed inside molds of certain dimensions. In the modern era, they are made from a mixture of clay, water, and some additives and are placed inside molds of certain dimensions and pressed in high-pressure presses, and placed inside an oven with a temperature of (1000) degrees Celsius, to obtain

the required rigidity. The temperature is controlled to obtain certain specifications such as changing color, bearing weight, and temperature (such as bricks intended for building furnaces) as well as moisture absorption and thermal insulation. Brick debris abounds on the right side of the city of Mosul,



especially the old city and the nearby neighbourhoods because it was built before the left coast (the new part of the city) and before the blocks were used in construction. They were grouped into piles in the destruction areas. Figure 6 (a and b).



Figure 6. The bricks materials rubble dumped in separate places in Mosul

Brick aggregate, a type of demolition and construction waste, is a demolition activities by-product. Although there are a large number of studies focusing on the use of reclaimed asphalt slabs and crushed concrete aggregates in many geotechnical applications, limited research has been conducted on the use of bricks. An experimental study demonstrated the physical properties of demolition waste materials to reuse as fill materials for engineering purposes [37]. The researchers presented a study of the physical properties of three commercial types of cement and crushed bricks. The first material was crushed bricks, and the other two were similar concrete materials with different degrees of processing. Geotechnical properties, such as particle shape, particle size distribution, total impact, antifreeze, and fracturing values were studied. The results displayed that the two crushed concrete materials that have been treated to different degrees have similar properties that depend on their structure, such as water absorption and mixture density. In another study, the geotechnical properties of crushed bricks were displayed and suggested to use in paving aggregate applications [38]. The material was collected for laboratory work from a

recycling facility in Victoria, Australia. The engineering properties of different percentages of crushed rock together with crushed brick mixtures obtained from large-scale experimental tests have been shown in this study. To determine the potential utility of crushed brick mixtures, the obtained engineering properties were compared with local road authority specifications currently used for lightweight paving or under-paving materials for drainage systems. The results of the laboratory tests indicated that, with an acceptable safety factor, up to 30% of crushed brick material could be added to the crushed rock mixture for applications for paving or under paving materials.

The results of a laboratory program on the categorization of recycled crushed bricks and an evaluation of its performance as pavement basic materials were reported [39]. To evaluate their performance as a base material of pavement, the properties of recycled crushed bricks were compared to specifications of the local Road Authority of Australia. The experimental program was extensive and involved tests such as particle size distribution, particle density, compaction to modified Proctor specification,

water absorption, CBR, Los Angeles corrosion test, triaxial test, repeated triaxial load, pH test, and organic content. The results showed that the crushed bricks should be mixed with other materials of higher durability to improve their performance. The corrosion loss value for Los Angeles was above the sub-base material limits specified for pavements. Geotechnical test results show that it may be necessary to mix crushed brick material with other recycled blends to improve its performance in sub-pavement applications and improve its durability. The shear strength of crushed bricks was above acceptable limits, particularly at high humidity levels. The repeated triaxial test proved that crushed bricks would perform satisfactorily at a humidity level of 65%. Repeated triaxial test results indicate that recycled crushed brick material and 65% water content are usable in under-pavement applications.

A comprehensive laboratory study of the geotechnical behaviors of various demolition and construction wastes, including used asphalt sheets, crushed concrete aggregates, and crushed brick aggregates in potential pavement applications was conducted [40]. The researchers concluded that crushed concrete mixtures have more resistance than natural granular aggregates, while other materials need some treatment with additives to be used as the base material.

Recently, a series of studies on the use of concrete rubble, asphalt aggregates, and bricks from demolition and construction rubble after being mixed with clay with low plasticity and used as paving materials for roads [25,26], [41-47]. The researchers concluded that demolition and concrete construction waste can be mixed with clay in specific proportions for the paving layer by methods to increase durability and reduce swelling and plasticity and reduce environmental and economic problems around the world. A study showed the effect of the construction and demolition materials on expansive soils from Mosul city-Iraq on soil consistent limits [48]. It was found that the liquid limit and plasticity index reduced significantly, and the reduction percent is controlled by the demolition type.

5. Conclusions

This study included a review of previous researches and studies that dealt with the reuse of demolition and construction waste for geotechnical engineering, such as improving the soil or using it as paving materials or under paving in the roads. The study included three materials from demolition and construction waste, which are concrete rubble, asphalt materials, and bricks. The following recommendations can be concluded from the study:

- With the beginning of the reconstruction operations of destroyed buildings and facilities, there is no clear plan for the process of dealing with demolition and construction waste.
- The major method of dealing with the demolition and construction debris is by moving it to other places randomly or irregularly burying it without any strategies.
- A small amount of demolition and construction debris was used as backfilling in a very specific area of the city, like Mosul university.
- Many previous studies in the world have shown the possibility of reusing demolition and construction waste, especially concrete, asphalt materials, and bricks, in paving layers or under paving (base and sub-base materials) for various types of roads.
- Several studies have shown the possibility of using demolition and construction waste, especially concrete, asphalt materials, and bricks, to improve the engineering properties of clay and organic soils such as increasing the resistance, reducing swelling and subsidence, and reducing plasticity.

The study recommends conducting future studies focusing on the reality of demolition and construction waste scattered throughout Mosul and proposing correct scientific ways to deal with it and use it for various engineering purposes.

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