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# Investigation of the Usability of Recycled Aggregate Obtained from Post-Earthquake Building Demolition Wastes on Highways: An Evaluation for Turkey

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***Abstract*** **-** It should be kept in mind that natural resources in our world are not infinite and will one day be exhausted if not used carefully. Increasing consumption in parallel with population growth and the uncontrolled release of wastes resulting from this consumption into nature disrupt the ecological balance and damage the nature. Wastes that can be recycled can be recycled through various physical or chemical processes. In this way, it is ensured that both natural resources are protected and waste materials with economic value are brought to the economy. In many developed countries, legal regulations have been introduced that encourage the recycling of waste materials and prohibit the disposal of recyclable materials. Developing countries, which are striving for development and facing economic difficulties, also need to put an end to waste waste in order to utilize natural resources efficiently and protect their natural resources. For this reason, waste materials with economic value should be recycled and reused.
In disasters such as earthquakes, if the damage and impact are large, a significant amount and volume of disaster waste is generated. After the earthquakes that occurred in our country on February 6, 2023, within the scope of damage assessment studies carried out by the MoEU in 13 provinces, it was determined that 263,800 independent units in 61,722 buildings were in need of urgent demolition, heavily damaged and demolished as of February 16, 2023. Accordingly, the amount of earthquake waste was preliminarily calculated and the estimated amount of waste to be generated on a provincial basis was calculated. The total amount of earthquake wastes is estimated to be between ~50 million tons and ~110 million tons. Earthquake wastes should be transported to temporary storage areas, where the materials in the wastes should be separated and reused, recycled/recycled/recycled to a large extent, and the remaining wastes should be disposed of within the framework of the provisions specified in the relevant regulations according to their hazardousness level.

***Keywords*****:** Construction Demolition Waste, Hot mix asphalt, recycled aggregate, Earthquake

## 1. Introduction

The 6-7 February 2023 Pazarcık and Elbistan earthquakes in Turkey caused great destruction and loss of life in the region. These two earthquakes with magnitudes of 7.7 and 7.6 affected the provinces of Kahramanmaraş, Hatay, AdCDWman, Gaziantep, Malatya, Kilis, DCDWrbakır, Adana, Osmaniye, Şanlıurfa and Elazığ. Since the epicentres of the earthquakes were close to the city centres, the impact area increased and a large amount of demolition waste was generated. In the report prepared by Istanbul Technical University, it is estimated that 138 million tonnes of rubble will be generated as a result of the removal of all debris [1]. When the amount of waste released from the demolition of damaged buildings in addition to the rubble is considered, the seriousness of the situation is more clearly understood (Figure 1). The Ministry of Environment and Urbanisation stated that a total of 229,000 houses in 13 provinces have been demolished or will be demolished due to severe damage, and emphasised that the identification works are still ongoing and that these numbers will increase. In the studies conducted, it is stated that it is not possible to specify an exact figure, but it will vary between approximately 138 million tonnes and 900 million tonnes [1]. The amounts of rubble released in the disasters that have occurred worldwide are presented in Table 1. In addition, the rubble mountain formed by earthquake wastes in Hatay province is given in Figure 2.

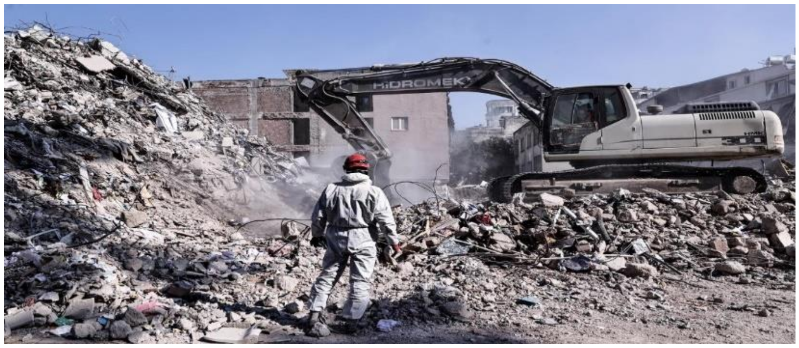

Fig. 1. On-site waste pile

Table 1. Some disasters and the amount of construction waste generated [2]

| Disaster Name | Amount of waste (million tonnes) |
|---|---|
| 2023 Kahramanmaraş Earthquake | 465 |
| 2010 Haiti Earthquake | 23-60 |
| 2009 L'agulia Earthquake | 1.5-3 |
| 2009 China Sichuan | 375 |
| 2005 US Hurricane Hurricane | 76 |
| 2004 Florida Hurricane Frances | 3 |
| 2004 Indian Ocean Tsunami | 10 |
| 2004 Indian Ocean Tsunami | 2 |
| 1999 Marmara Earthquake | 13 |
| 1995 Japan-Kobe Earthquake | 15 |

Fig. 2. Mountain of rubble from demolition waste

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## 2. Construction Demolition Waste (CDW or C&D waste)

The resulting waste materials are considered as construction and demolition waste (CDW) and are an environmentally and economically important waste. The European Union has declared that 31% of all waste consists of C&D waste [3]. Construction and demolition wastes are known to cause serious air, water and soil pollution [4]. Effective management of construction and demolition waste has become a priority task for sustainable development programmes worldwide. It is estimated that approximately 450 million tonnes (MT) of construction and demolition waste is generated in the European Union (EU) each year, of which only 28% is recycled and the remaining 72% is landfilled [5].In the United States, 484 million metric tonnes of construction waste was generated in 2014. In China, these wastes constitute 30-40% of the total amount of waste and only 5% is recycled [6]. In France, 227.5 metric tonnes and in India, 530 million tonnes of C&D waste is generated [7].

Doğdu and Alkan, in their study, calculated the approximate amount of construction demolition waste for 11 provinces provinces affected by Kahramanmaraş and Hatay earthquakes. The calculation results are presented in Table 2.

Table 2. Approximate amounts of demolition waste for 11 provinces during the 6 February earthquakes [2]

| **(tonne)** | **Approach mass waste** | **Dangerous substances** | **Mixture of soil and stones** | **Bituminous mixtures and wood waste** | **Mineral fraction waste** | **Reinforced concrete waste quantity** | **Amount of scrap iron waste** |
|---|---|---|---|---|---|---|---|
| Adana | 552.024,00 | 8.280,36 | 92.740,03 | 123.653,38 | 325.694,16 | 220.809,60 | 5.330,00 |
| Adiyaman | 10.519.872,00 | 157.798,08 | 1.767.338,50 | 2.356.451,33 | 6.206.724,48 | 4.207.948,80 | 101.576,00 |
| Diyarbakir | 1.608.574,00 | 24.128,61 | 270.240,43 | 360.320,58 | 949.058,66 | 643.429,60 | 15.532,00 |
| Elazig | 1.899.172,00 | 28.487,58 | 319.060,90 | 425.414,53 | 1.120.511,48 | 759.668,80 | 18.338,00 |
| Gaziantep | 5.451.985,00 | 81.779,78 | 915.933,48 | 1.221.244,64 | 3.216.671,15 | 2.180.794,00 | 52.642,00 |
| Hatay | 40.252.685,00 | 603.790,28 | 6.762.451,08 | 9.016.601,44 | 23.749.084,15 | 16.101.074,00 | 388.664,00 |
| Kahramanmaras | 18.573.962,00 | 278.609,43 | 3.120.425,62 | 4.160.567,49 | 10.958.637,58 | 7.429.584,80 | 179.343,00 |
| Kilis | 470.118,00 | 7.051,77 | 78.979,82 | 105.306,43 | 277.369,62 | 188.047,20 | 4.539,00 |
| Malatya | 13.374.053,00 | 200.610,80 | 2.246.840,90 | 2.995.787,87 | 7.890.691,27 | 5.349.621,20 | 129.135,00 |
| Osmaniye | 3.012.757,00 | 45.191,36 | 506.143,18 | 674.857,57 | 1.777.526,63 | 1.205.102,80 | 29.090,00 |
| Sanliurfa | 1.152.481,00 | 17.287,22 | 193.616,81 | 258.155,74 | 679.963,79 | 460.992,40 | 11.128,00 |
| **Total** | 96.867.683,00 | 1.453.015,25 | 16.273.770,74 | 21.698.360,99 | 57.151.932,97 | 38.747.073,20 | 935.317,00 |

In general, most of the CDWs are obtained from reinforced concrete structures and 65-70% of the total waste percentage is composed of concrete [8]. The general compositions of CDWs are given in Table 3.

Table 3. CDW contents

| | **References** | | | |
|---|---|---|---|---|
| Components | [9] | [10] | [11] | [12] |
| Concrete and mortar | 69.8 | 70 | 72.5 | 71.2 |
| Natural aggregate | 25.1 | 25 | 21.5 | 0 |
| Brick | 0 | 0 | 0 | 26.16 |
| Wall materials | 3.4 | 3.7 | 0 | 0 |
| Ceramic | 0.219 | | 1 | 2.3 |
| Various bituminous parts | 0 | 0 | 4 | 0 |
| Concrete containing metal particles | 1.1 | 1.121 | 0 | 0 |
| Textile fibre concrete | 0.146 | 0.146 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| Gypsum plaster | 0.103 | 0.103 | 0 | 0 |
| Other | <0.1 | <0.1 | 1 | <0.4 |

## 3. Separation of Construction Demolition Waste

CDWs need to be properly segregated. Improper sorting of these wastes leads to significant environmental and economic consequences, including inefficient resource use and missed recycling opportunities. CDWs are made up of different components, which need to be properly categorized. These concerns, often caused by the variability in waste composition and the presence of contaminants, lead to reduced market demand for recycled products [13]. Adding to these complexities is the practice of off-site sorting, which is often preferred by contractors, despite the fact that some countries require source separation of CDW [14]. In light of these challenges, it is vital to improve the CDW sorting process to ensure the quality of recycled materials. The classification of CDW ranges from basic centralized and decentralized systems to more complex automated robotic solutions [15]. Traditional sorting systems rely on heavy machinery, including hoppers, crushing systems, magnetic separators, sieves and conveyors, to separate the CDW. These systems are often complemented by manual sorting in the final stages of the process to further improve the purity of the material [16]. However, manual sorting of CDW is often considered inconsistent, costly, unreliable and dangerous for the workers involved in the process [17]. To overcome these drawbacks, the integration of robotic systems with IAF sorting is gaining interest, driven by recent advances in machine/deep learning and convolutional neural networks. This shift towards automated (and autonomous) sorting is transforming waste management practices by aiming to replace human involvement in both on-site and off-site sorting operations with more accurate, efficient robotic systems [18]. This transition is seen as an important step in improving waste management efficiency and contributing to sustainable practices in the construction industry. However, the effectiveness of these robotic systems depends significantly on their ability to accurately detect and classify different types of waste, a problem that is being actively addressed by recent advances in machine learning and artificial intelligence. This research area is rapidly evolving and has important implications for the optimization and efficiency of automated sorting systems. Studies have shown that automatic classification of CDWs can significantly reduce costs [17]. Some of the items during the classification and identification processes are presented in Figure 3.

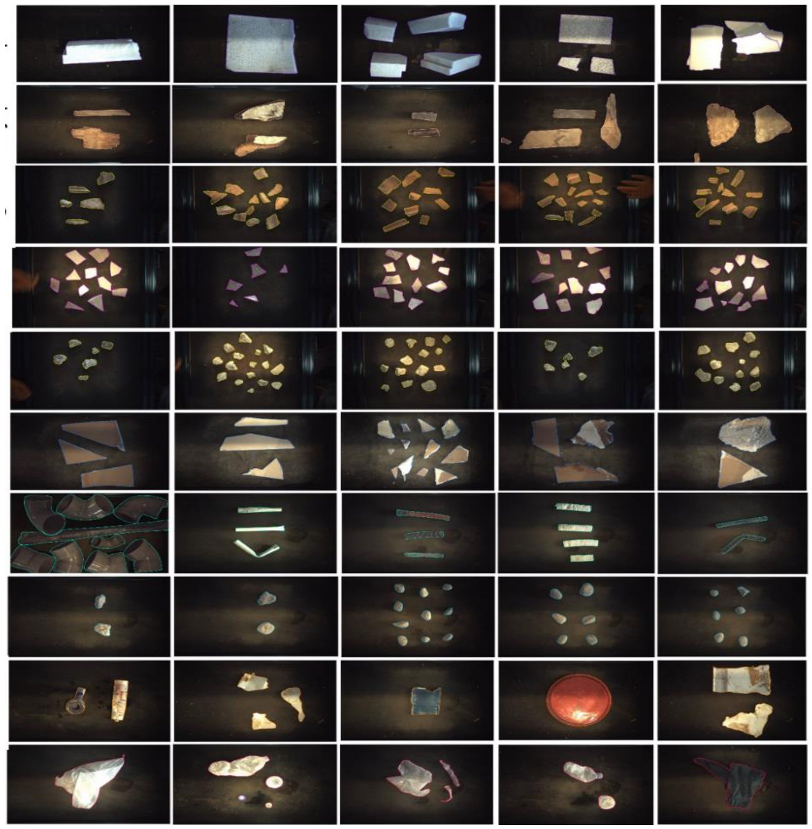

Fig. 3. Classified wastes

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## 4. Aggregate obtained from construction demolition wastes

Concrete constitutes a large part of CDWs. Reinforced concrete mass may contain mortar, aggregate and reinforcement. In this process, the idea of reducing the consumption of natural resources was adopted and the first focus was on aggregate. Concrete contains 65-70 per cent aggregate by volume. Natural aggregates are an important component material and are constantly depleted due to intensive use in construction projects, causing significant damage to the ecosystem [19], [20]. In addition, large amounts of energy are consumed in the extraction, processing and transport of natural resources. It is known that the extraction of natural aggregates has negative impacts on the environment and also affects river beds. The International Association of Specialists in Construction Materials Systems (RILEM) has organised many conferences and published papers on the use of REA in construction, and the European Union countries have introduced requirements in legislation for the use of recycled materials in areas suitable for the production of designated recycled materials. In addition, in most countries, specific standards and appropriate legislation on Recycled Aggregate have been established. Japan considers Construction and Demolition Waste (C&D) as a by-product in new constructions, has published 'Specification for the Use of RA (Recycle Aggregate) and RC (Recycle Concrete)', has established many factories capable of producing 100 tonnes of RA per hour to process waste concrete, and has made it obligatory to have machines capable of crushing waste concrete in new constructions. Germany is recognised as one of the pioneer countries in the field of CDW. In Berlin alone, there are 20 plants recycling waste concrete.

In recent years, many studies have been carried out on the reuse of materials in demolition waste management. It has been found that using demolition waste to produce recycled aggregate (RDA) is a viable option not only to avoid the environmental impact caused by demolition waste landfills, but also to improve resource utilisation and reduce the consumption of natural aggregate (NAG) [21]. DA produced using demolition waste can be used as construction material. For example, RA can be used in road construction, where it can be used as a partial or complete substitute for natural gravel as backfill for road foundations or sub-base, and can be used in road layers for either rigid or flexible pavement [22]. In addition, RA is used in the production of concrete-related products such as concrete blocks, concrete kerbs and floor In addition, due to its high porosity, RA is used in the production of functional materials such as sound insulation [23] and permeable concrete. However, RA is somewhat lacking in performance compared to DA. RA has higher and water absorption, the density of RA is lower than that of DA, and the mechanical properties of RA are relatively Therefore, when RA is used to produce recycled concrete, it generally cannot completely replace DA. In fact, by changing the amount of RA [24] or increasing the amount of cement [25], recycled concrete with the same strength as natural concrete can be produced. Therefore, it is technically possible to produce recycled concrete using RA [26].

When hot mix asphalts are properly designed according to current protocols, one can easily argue that constructing one kilometre of motorway (10 m platform width) with 45 cm thick sub-layers (base and sub-base) would require 12,000 tonnes of aggregate, and then paving it with 20 cm thick bituminous layers would require 250 tonnes of binder and an additional 5,150 tonnes of aggregate [27]. It is this aggregate, which constitutes the highest percentage of the total content, that has the most dominant and decisive influence on the properties of road asphalt pavements. Many studies have been carried out on the use of CDW and aggregate in CDW with different approaches in bituminous hot mixes. At present, research on the application of CDWs in road engineering is mainly focussed on the pavement base layer, sub-base and subgrade, and fruitful results are being achieved both in theoretical research and in engineering practice [28]. However, research on its application in the asphalt pavement surface layer is still under development.

The physical and mechanical properties of aggregates derived from demolition waste are quite different from those of natural aggregates and these also directly affect the performance of asphalt. Bricks have the largest crushing value, the highest water absorption and the worst adhesion to asphalt among the SWA. Particle separation is more likely to occur under freeze-thaw environmental conditions [28]. According to the relevant regulatory requirements, bricks are only applicable to the foundation and sub-base paving of low-grade roads. At the same time, the mortar is mainly located around the surface of the concrete, the content is small, and can be ignored. Many studies have concluded that recycled concrete aggregates have better applicability in the surface layer of asphalt pavement. Nevertheless, the high water absorption of recycled fine concrete aggregates makes them unsuitable for asphalt pavements. The particle size distribution of aggregates obtained from demolition waste is uneven. Some important technical indexes such as water absorption and crushing value are quite different from natural aggregates, so it is not suitable to mix all aggregates in asphalt mix design. Meanwhile, the surface of RAs contains many pores, which will increase the optimum asphalt content and reduce the economic efficiency of the application. In addition, as already mentioned, the full utilisation of concrete aggregate obtained from CDWs carries some disadvantages. It should be analysed in detail, especially in terms of fatigue performance. In the referenced study, the fatigue properties of asphalt mixtures containing RA were investigated in detail [28].

Kareem et al. investigated the use of different percentages of CDW in asphalt mixtures. As a result of laboratory experiments on asphalt samples containing 0, 25, 50 and 75% CDW, it was determined that CDW was broken during mixing and compaction and the coarse aggregate ratio decreased and the fine aggregate ratio increased. In addition, it was also observed that the fracture rate increased as the percentage of CDW increased [29]. In their study, Gomez-Meijide and Perez focused on the concept of sustainable cold mix asphalt. In this context, cold mix asphalts containing 100% RA were obtained. As a result of the laboratory tests, very satisfactory results were obtained in standard asphalt tests such as ITS and ITSM [30]. In another study, Gomez-Meijide et al. carried out various mechanical tests on cold asphalt mixtures containing 100% CDW. It was found that the mixture containing CDW offered higher stiffness values compared to the mixture containing natural aggregates, but they required higher bitumen and water contents. The decrease in temperature sensitivity was considered as a positive development and fatigue resistance increased [9]. Table 6 shows the studies in the literature in which ITSs are used.

Table 5. Studies in the literature

| Reference | Usage |
|---|---|
| [28] | CDW aggregates were used as coarse aggregate. |
| [29] | Three different proportions (25%, 50%, 75%) were used instead of fine aggregate. |
| [8] | It was used instead of aggregate in the foundation layer. |
| [31] | Aggregates were used as coarse and fine aggregates. |
| [12] | They investigated its usability as an aggregate substitute. |
| [30] | It was used as a cold mixture. |
| [9] | It was used as a cold mixture. |
| [10] | It was used as a cold mixture. |
| [32] | Hot mix asphalt samples containing 0%, 5%, 10%, 10%, 20% and 30% waste aggregates instead of natural aggregates were evaluated. |

## 5. Results and Discussions

This study has comprehensively addressed the use of construction demolition waste (CDW) as substructure and superstructure material for highways. In the light of the studies in the literature and experimental findings, it has been clearly demonstrated that CDW can be recycled into an economically and environmentally valuable resource. Especially after large-scale disasters such as earthquakes, the utilization of high-volume demolition wastes with sustainable methods makes significant contributions to both the conservation of natural resources and the reduction of environmental impacts.

Demolition wastes can be successfully utilized in critical layers such as road subbase and foundation, especially when recycled aggregate (RA) is utilized. Although the physical and mechanical properties of RA differ from those of natural aggregates, the performance of these materials can be improved with appropriate design and processing techniques. For example, studies have shown that the high water absorption and low density properties of CDW can be compensated for by optimizing cement or binder proportions. The use of such materials reduces the need for natural aggregates and reduces the storage costs of demolition waste.

Studies on the use of RA in asphalt mixtures used in road pavements have shown that this material can be a valuable component in sustainable asphalt production. Especially in cold mix asphalts, satisfactory mechanical properties have been obtained with the use of 100% RA. However, the high water absorption rate and low strength of RA in hot mixes may require special treatments and modifications prior to application. Findings in the literature that RA improves the fatigue strength and temperature sensitivity of asphalt mixtures show the potential of this material in performance-oriented asphalt production.

Recycling of CDW not only reduces natural resource consumption and environmental damage, but also provides economic gains. In this context, the reintroduction of CDW into the construction industry allows for reduced environmental costs and improved waste management processes. For example, RA utilization standards in countries such as Germany, Japan and the United States show that this material can be safely used in both infrastructure and superstructure projects.

Effective management of CDW is important in line with sustainable development goals. In Turkey, the Regulation on the Control of Excavated Soil, Construction and Demolition Waste encourages the use of these wastes as infrastructure materials. However, the quality standards of recycled materials need to be improved and their areas of use need to be expanded. Furthermore, the application of robotic and artificial intelligence-based sorting technologies can make the recovery processes of CDW more efficient.

This study has demonstrated that CDW has the potential for a wide range of applications, especially in highway engineering. However, further research is required in terms of performance, durability and economic feasibility before materials can be fully adopted. Future studies could examine the role of HMA in the production of high-performance mixtures, leading to a more widespread use of these materials in pavements. In conclusion, the use of CDW in highway infrastructure and superstructures presents a great opportunity to improve environmental sustainability and conserve natural resources. With appropriate management strategies and technological innovations, these wastes could become a key component in future construction projects

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