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THE CARBON COST OF THE BUILDINGS DESTROYED IN YALOVA IN THE 1999 MARMARA EARTHQUAKE

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ABSTRACT

Natural disasters have some environmental impacts as well as economic impacts. For example, when disasters such as earthquakes are not prevented, efforts must be made to minimize the economic and environmental costs that may arise. Although the interest of society and governments in the economic consequences of the earthquake is more intense, environmental effects should also be calculated, and the significance of the situation should be shown. Herein, it estimated the CO_2 emissions caused by debris transport from the 1999 Marmara earthquake in Turkey in Yalova, a province of Turkey, and the reconstruction of the destroyed structures. As a result of the calculations, it has been found that 2031 x 10^3 tons of CO_2 were released during the transport of debris and reconstruction of 9462 building that was destroyed before the end of their life in Yalova. Moreover, 42% of these emissions are caused by concrete alone. In addition, this value corresponds to 0.73% of the CO_2 emitted in Turkey in 1999.

Keywords: Carbon dioxide emission; Debris; Marmara earthquake

INTRODUCTION

Climate change, which has emerged as a result of life, occupies the global agenda so much that it has led to the creation of various protocols and road maps today (such as the European Commission-European Green Deal, Global Concrete, and Cement Association-zero emission road maps). Even if the increase in greenhouse gas concentration is not the only factor in climate change [1], the most crucial factor is the CO_2 emissions resulting from industrial and living organism activities [2]. Efforts are made to reduce CO_2 emissions through methods such as technological development in production facilities [3], use of waste energy [4], use of renewable energy sources [5], and preference of hydroelectric facilities, which are more harmless than other methods of electricity generation [6]. When analyzed on a sectoral basis, the building sector consumes approximately 50% of the raw materials extracted from the earth [7], is responsible for 36% of global energy use, and is among the leading causes of climate change, with 39% of carbon dioxide emissions originating from energy use [8]. Moreover, 35% of the total waste generated in parallel with all this energy use originates from the construction sector [9].
Earthquake, which is in the category of natural disasters, causes economic and moral losses that are difficult to compensate for since the structures have not received adequate engineering services and due to the lack of

supervision of the provisions of the construction regulations. On 17 August 1999, the Marmara earthquake with a magnitude of 7.6 (Mw), with a maximum intensity of X according to the Mercalli intensity scale and lasting 45 seconds, occurred in Turkey. Due to this earthquake, 2504 people lost their lives, 6042 people were injured, and 9462 structures were severely damaged in Yalova, a province of Turkey [10]. The economic costs of the 1999 Marmara earthquake were calculated, and the losses were somehow compensated. According to the evaluation of the World Bank, the direct cost of the 1999 Marmara earthquake to Turkey (housing, education, health, infrastructure, etc.) was around 3-6.5 billion dollars [11]. The majority of the costs mentioned here are based on due to factors such as not designing buildings to be earthquake resistant (defective materials, poor engineering service, ignored building regulations), not being built resistant to earthquakes (poor workmanship), or making undesirable changes during their use (modifications that change the rigidity of the structure) [12], [13]. It has been reported that the most common cause of damage in the 1999 Marmara earthquake was the short-column effect, which is a structural defect [12].

There are some environmental effects in addition to the calculable and compensable economic effects of the earthquake. The destruction of structures that have not completed their service life yet due to poor quality material use and poor engineering service brings environmental loads, and the evaluation of these environmental loads can be evaluated with the Life Cycle Analysis (LCA) method [14]–[16]. Infrastructures and superstructures demolished or damaged by earthquakes generate waste and debris at an intensity that is not usually expected [17]. Some of this debris and waste can be recycled or stored in an area. Some studies involve the management of construction waste, examining the environmental and economic effects of management methods [18]. For instance, Blengini (2009) suggested that recycling waste and debris that emerged after a disaster is environmentally beneficial [19], and Amato et al. (2019) suggested that although the decomposition process in the demolition area is more environmentally friendly, it is more economical to transport the wastes to the landfill without any separation-grinding process [20]. The environmental effects of the earthquake are not only limited to the removal of the resulting wastes, but also have effects such as explosion, fire, the release of harmful gases, and leakage of harmful chemicals to water and soil that may occur during and after the earthquake. Kosaka et al. (2012) studied the removal of radioactive iodine and cesium detected in raw water due to an explosion at a nuclear power plant in the Great East Japan Earthquake [21].

The motivation of this study is the environmental effects, which have not been taken into account and investigated in previous studies, of a case (1999 Marmara Earthquake). In this context, the environmental effects arising from the demolition of 9462 buildings that were heavily damaged due to the Marmara earthquake and assumed that they have not yet completed their service life has assessed in Yalova. Environmental impacts during the production and supply of used materials for the construction of the buildings and debris removal were calculated. In this assessment, the environmental impacts that occur during the service life of the building have been ignored. This study includes calculating embedded energy values and CO_2eq resulting from the production of the materials used in constructing the demolished buildings and transporting the debris to the landfill using the ICE V2.0 database.

MATERIAL AND METHOD

Database

In this study, ICE V2.0 (The Inventory of Carbon and Energy) database was used to calculate the embedded carbon and embedded energy values of buildings. ICE V2.0 is an LCA-based database created at the University of Bath, England [22]. The data in the ICE V2.0 database, which creates an inventory of the embedded carbon and embedded energy values of building materials, was created by collecting information from various books, articles, and conference texts. The values in the inventory, in which 34 building material groups are listed, include the values from cradle to door. Although it is challenging to meet the embedded carbon and embedded energy value of a material in an internationally accepted typical value, the values given in the ICE V2.0 database have proven to be more reliable than the values given in other databases [23].

System Boundary

In the province of Yalova, which is the subject of the study, some of the debris revealed in the 1999 Marmara earthquake was used as a sea fill material, and some of it was transported to the rubble waste area (Figure 1). In this study, the transport distance of the debris was taken into account as 50 km. It is assumed that the heavily damaged buildings (9462 collapsed/destroyed) have a height of 3 m, an average of 5 floors, and a building area of 125 m2, and the calculations were made accordingly. The interior heights vary due to the 70% slope in the attic floors that are open to using. It has been accepted that rockwool is preferred for thermal insulation and tiles are preferred for the roof covering, and a reinforced concrete raft foundation is applied on lean concrete after waterproofing and thermal insulation, respectively. Correction screed, polyethylene mattress, laminate parquet, or ceramic are made on the foundation, respectively. Column dimensions of 30x30 cm, beam dimensions of 25x40 cm, and normal flooring in the buildings are assumed. The building elements and used building materials are given in Table 1, and the floor plans of the buildings are given in Figure 2.

Figure 1. Research limits (Yalova Province) (www.google.com/maps).

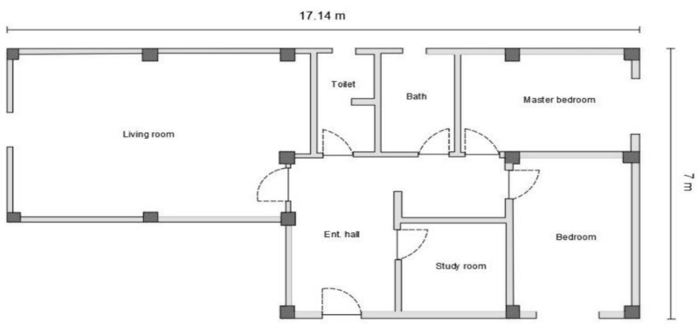


Figure 2. Floor plan of buildings.

Table 1. Construction materials.

Materials of basic structural elements of buildings	
Structural element	Construction material
Base	Raft foundation
Column	Reinforced concrete
Beam	Reinforced concrete
Floor	Reinforced concrete
Wall	Hollow brick
Roof	Reinforced concrete and roofing tile
Door	Wood

RESULT AND DISCUSSION

Construction Materials Production

In the study, firstly, the embedded carbon and embedded energy values of the materials used in the buildings from the cradle to door were calculated. In order to reach these values, the quantities of the materials used in a building were subtracted, and the total amount of debris in the region was determined. The technical sheets of the building material manufacturers were used in the unit weight calculations of the materials. Calculations made using the ICE V2.0 database are presented in Table 2.

Table 2. Embedded energy and CO_2eq values of building materials

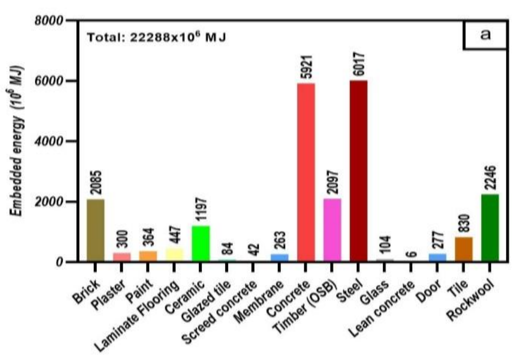
Construction material	Quantity (kg)	Embedded Energy (Mj)	kgCO_2eq
Brick	695,002,824	2,085,008,472	166,800,677
Plaster	310,012,968	300,712,579	48,362,023
Paint	5,204,100	364,287,000	15,143,931
Laminate flooring	37,299,204	447,590,448	15,665,665
Ceramic	99,805,176	1,197,662,112	77,848,037
Glazed tile	63,868,500	84,945,105	14,114,938
Screed concrete	49,807,968	42,336,772	6,773,883
Membrane	5,175,714	263,961,414	2,536,099
Concrete (C25)	7,592,072,250	5,921,816,355	857,904,164
Timber	139,838,898	2,097,583,470	62,927,504
Steel	278,580,204	6,017,332,406	518,159,179
Glass	6,982,956	104,744,340	6,354,489
Lean concrete	8,865,894	6,206,125	886,589
Door	29,218,656	277,577,232	9,642,156
Tile	127,737,000	830,290,500	61,313,760
Rockwool	133,726,446	2,246,604,293	149,773,619
Total		22,288,658,625	2,014,206,720

Transporting Debris

In this study, it was assumed that the debris was transported to an area 50 km away on average. An average lorry/truck consumes 0.3 L/km of fuel, emits 2.68 kgCO_2eq for each 1 L of diesel fuel consumption and can take a load of 21-24 tons [24] . It is assumed that the truck used in the study can take a load of 24 tons. The CO_2eq value was calculated as 16786.2 kg in order to take the rubble transported in 404 trips to the landfill.

Assessment

The amount of energy consumed only in the production of building materials is presented in Figure 3a of 9462 buildings that were destroyed in Yalova due to the 1999 Marmara earthquake. As can be seen from the figure, steel has the highest embedded energy value of 6017x10^6 MJ, followed by concrete, rock wool, mold, and brick, respectively. The total embedded energy value of all structures is 22288x10^6 MJ. The point to be noted here is the assumption that the severely damaged and demolished structures have not yet completed their service life and that this energy previously spent in the construction of these structures is spent again in the rebuilding of the structures. One of the most critical factors for sustainable construction is the service life [25], [26]. Keeping the service life long is very beneficial in terms of reducing resource consumption and greenhouse gas emissions. The amount of CO_2eq caused by the production of building materials used in the construction of 9462 buildings, and the process of transporting the construction debris to the landfill after demolition is presented in Figure 3b. The production of building materials and the transport of rubble caused a total of 2031x10^3 tons of CO_2eq. Among the building materials, concrete was by far the product with the highest CO_2 cost, in contrast to its embedded energy values. Concrete was followed by steel, brick, and rockwool, respectively. While the embedded energy value of steel is only about 2% higher than concrete, the embedded carbon value of concrete is about 65% higher than steel. Undoubtedly, the share of cement production, which accounts for 6-7% of global CO_2 emissions, is relatively high in these results [27], [28].



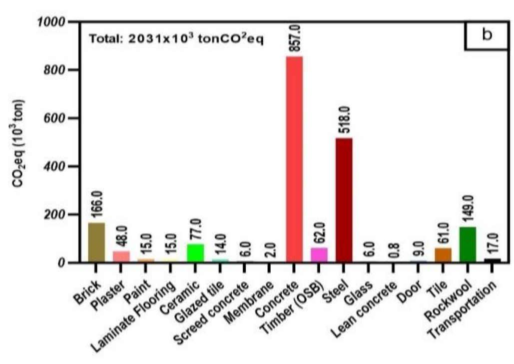


Figure 3. Total embedded energy of building materials (a), CO_2eq including debris transport (b).

The distribution of total CO_2 emissions by building material types is presented in Figure 4. Accordingly, concrete is responsible for almost half of the total CO_2 emissions. Concrete is followed by steel, brick, and rockwool, respectively. As it can be understood from here, it is necessary to either reduce the use of concrete or produce environmentally friendly concretes in order to reduce global CO_2 emissions.

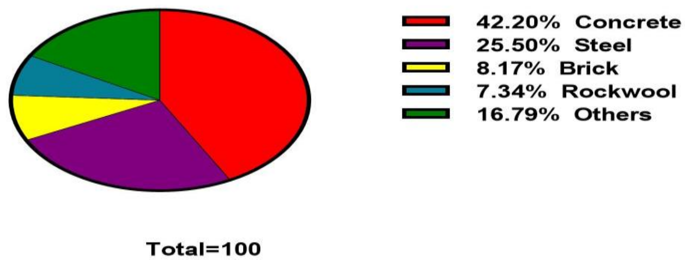


Figure 4. Distribution of CO_2 emissions by building material types.

CONCLUSIONS

- The demolition of structures that do not receive adequate engineering service or that have undergone changes that will damage the dynamic behavior of the structure for any reason brings ecological costs as well as financial costs. In this study, which aims to calculate the ecological cost of the damage caused by the 1999 Marmara earthquake in Yalova, the following conclusions were reached;
- The total embedded energy cost of the buildings destroyed in Yalova in the 1999 Marmara earthquake is $22288x10^6$ MJ.
- The CO_2eq released during the construction of the buildings and the removal of the debris is $2031x10^3$ tons.
- Concrete used in buildings is alone responsible for 42% of the total CO_2 emissions. Steel follows concrete with a share of approximately 26%.

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