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Investigation of the Effect of Selection of Construction Materials for Radiotherapy Centers

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Today, with the increasing use of various forms of radiation, all biological organisms are put at risk. Radiation science for medicine, agriculture, industry and military purposes has grown wide. To be protected from the harmful effects of radiation, attention should be paid to the time, distance and shielding rules. Shielding process varies according to the types of materials to be used. Turkey has the most abundant reserves of barite, which is a kind of heavy aggregate. Barite is experimentally used as a heavy concrete aggregate for radiation shielding purposes. In the present study, at first the shield thickness of the designed radiotherapy centre is computed according to the normal and heavyweight concretes. Then, the effect of type of material on the design of the radiotherapy centre is examined carrying out static and structural analyses.

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1. Introduction

Heavyweight concrete has been widely used for protection against radioactive rays in nuclear power plants, medical units, and in structures where radioactive impermeability is required [1]. With the development of technology in a variety of fields, it becomes important to take account of many parameters in building construction. Besides architectural aspect the physical and mechanical properties of building materials and also protection against radiation are important in a building construction [2]. The choice of the linear attenuation coefficient of a shielding materials μ, which is defined as the probability of a radiation interacting with a material per unit path length, is an important quantity and has to be known. The magnitude of linear attenuation coefficient depends on the incident photon energy, the atomic number and the density ρ of the shielding material [3]. When density of shield concrete is increased, its thickness can be reduced. In order to increase density of shield concrete, the percent of aggregate in this concrete has to be increased [4]. The type and quantity of aggregate in the concrete are important components for radiation protection properties of concretes. Using barite ($BaSO_4$) in building construction surely would be a good choice for protection against radiation, but this is not feasible as there is not enough barite reserve in the world [5].

The effects of radiation on an organism depend on the effects of the absorbed radiation on the cells of which the organism is composed. The cellular changes caused by exposure to electromagnetic energy are in turn caused by chemical reactions following the absorption of photons by molecules of the cell. The effect on the cells depends on the presence of absorbing molecules within or around the cells [6]. The need for safeguarding against significant and continuing radiation exposure is based on evidence of harmful biologic effects [7]. Radiation is dangerous for cells and they should be protected. This can be done by taking into account three main factors, namely time, distance and shielding [8].

2. Materials and methods

The first step in any room planning for radiotherapy services is to establish the design criteria. These criteria comprise (i) the limitations imposed by the allowed dose equivalent rates in different areas of the facilities and (ii) the existing space for construction [9]. In this study, the choice of materials in the construction of a radiotherapy centre was investigated and the architecture of the first radiotherapy centre is designed. There are two rooms in one radiotherapy unit design.

The transmission of the barrier, required to reduce the primary radiation field to the dose limits outside the barrier is given by [9]

$$B_{\rm prim} = \frac{P d_{\rm pri}^2}{WUT}, \qquad (1)$$

where P (Sv/week) is the dose per week outside the barrier (shielding design goal); $d_{\rm pri}$ (m) is the distance from the x-ray target to the point to be protected, which generally varies between 3 and 6 m, W is the workload, or absorbed dose per week at 1 m from the target (Gy/week), U is the use factor, the fraction of the beam-on time, during which the primary beam is directed to the barriers, and T is the occupancy factor, a factor that takes into account for the occupancy of the area in question.

The attenuation coefficient of gamma rays was determined by measuring the fractional intensity N_x of radiation passing through the material of thickness x, as compared to the source intensity N_0. The linear attenuation coefficient μ has been obtained from the solution of the exponential Beer-Lambert's law [10]

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$$N_x = N_0\,\mathrm{e}^{-\mu x}. \quad (2)$$

Half-value layer (HVL) and tenth-value layer (TVL) are the thicknesses of an absorber that will reduce the gamma radiation to half and to tenth of its intensity, respectively. These are obtained by using the following equations [11]

$$\mathrm{HVL} = \ln\frac{2}{\mu}, \quad (3)$$

$$\mathrm{TVL} = \ln\frac{10}{\mu}. \quad (4)$$

The thickness of the barrier is then evaluated by applying the TVLs data, based on the energy of the photons and type of shielding material. In this case, the number of TVLs is given by [12]

$$n = -\log(B_{\mathrm{pri}}).$$

The thickness of the barrier is

$$X = n\mathrm{TVL}.$$

Figure 1 shows a three-dimensional image of the radiotherapy center. The radiotherapy center was designated having two rooms. The rooms were designated to be square sized with dimensions of 7.5 meters and height of 6.5 meters. According to project, the radiotherapy center was selected to be built of steel of class S420 and of concrete of class C30. Properties of the concrete used in this study are given in Table I.

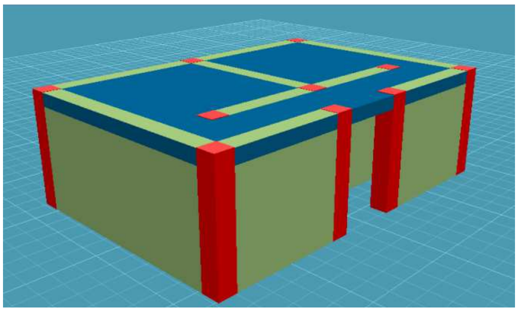

Fig. 1. The project of studied radiotherapy center.

TABLE I

Properties of the concrete.

Materials	Unit weight [kg/dm^3]	Linear attenuation coefficient μ
Normal concrete	2.4	0.078
Heavyweight concrete	3.4	0.048

The results obtained using the above described properties of materials are given in Table II.

TABLE II

Radiotherapy center dimensions [cm].

Materials	Slab thickness	Wall thickness
Normal concrete	120	140
Heavy concrete	75	90

The design of the radiotherapy center was made using static analysis program Sta4CAD and finite element analysis program SAP2000, considering normal concrete and heavy concrete as building materials. The analysis results for the construction period and earthquake displacement analysis results for considered concrete materials are given in Table III.

TABLE III

Construction period and earthquake displacement for designs based on normal concrete and heavy concrete.

	Period			Displacement [mm]	
	x	y	z	∂x	∂y
Normal concrete	0.0357	0.0332	0.0214	0.1117	0.0970
Heavy concrete	0.0411	0.0422	0.0269	0.1480	0.1910

After the analysis, quantities of the used materials were obtained and the results are given in Table IV.

TABLE IV

Quantities of steel and concrete necessary for construction.

Total	Normal concrete	Heavy concrete
Reinforcement steel [kg]	61153.1	33163.6
Concrete [m^3]	929.0	557.8

3. Conclusions

Calculated thickness of the heavy concrete shielding walls is about 50% less than that of normal concrete wall. Therefore shear wall reinforcement is increased in design with heavy concrete.

It is observed that, the mass and rigidity centres of the designed radiotherapy centre are nearly coincident for the solutions including normal concrete as well as heavyweight concrete. The earthquake and the strength of the centre of mass is distributed system here. The behaviours of the building against earthquakes radiotherapy centre therefore constitute irregularities.

The centre of rigidity of factors that affect the structures, such as construction period and displacements are very close to both the material and show that it is safe to be done by heavy concrete design to reduce design section thickness by heavy concrete. This study results; Selection of the heavy concrete building in the centre of radiotherapy has been shown to positively affect construction.

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