

# World Housing Encyclopedia

*A Resource on Construction in Earthquake Regions*



an initiative of  
Earthquake Engineering Research Institute (EERI) and  
International Association for Earthquake Engineering (IAEE)

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## HOUSING REPORT

### RC Structural Wall Building (Tunnel form building)

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<b>Report#</b>	101
<b>Last Updated</b>	
<b>Country</b>	Turkey
<b>Author(s)</b>	Ahmet Yakut, Polat Gulkan,
<b>Reviewers</b>	Svetlana N. Brzev,

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### Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John

## **General Information**

<b>Building Type:</b>	RC Structural Wall Building (Tunnel form building)
<b>Country:</b>	Turkey
<b>Author(s):</b>	Ahmet Yakut Polat Gulkan
<b>Last Updated:</b>	
<b>Regions Where Found:</b>	<p>Buildings of this construction type can be found in densely populated urban areas with limited land available for development. During the last decade, tunnel form buildings have also been the choice for rebuilding earthquake affected towns and urban areas because they fulfill the requirements of easy and rapid construction, and because their acknowledged excellent earthquake performance that makes them popular with occupants. This type of housing construction is commonly found in both sub-urban and urban areas. The use of 'suburban' in this text does not correspond to its commonly understood connotation in, e.g., the USA. We mean districts and areas in newly developed parts of urban areas that are located on the outskirts or peripheries of existing settlements.</p>
<b>Summary:</b>	<p>This type of rapidly constructed, multi-unit residential form has been used in Turkey since the late 1970s and early 1980s. It has demonstrated superior earthquake resistance and has also been increasingly utilized as permanent housing in post-earthquake reconstruction programs. Initially, the tunnel form building was targeted for multi-unit residential construction for public or privately sponsored housing projects. Typically, a single building may contain 15 or more stories and up to 40 or 50 residential units. This contribution has been motivated by our intention to not only familiarize readers with the architectural or structural features of the building type, but to also underscore its noteworthy seismic performance that stands in stark contrast to Turkey's recent experience.</p>
<b>Length of time practiced:</b>	Less than 25 years
<b>Still Practiced:</b>	Yes

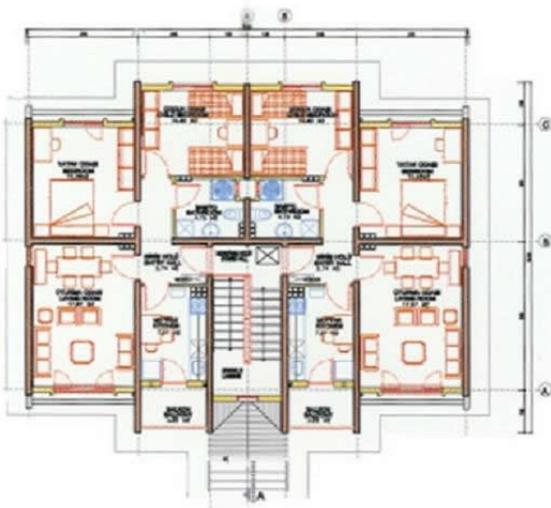
<b>In practice as of:</b>	
<b>Building Occupancy:</b>	Residential, 20-49 units
<b>Typical number of stories:</b>	10-15
<b>Terrain-Flat:</b>	Typically
<b>Terrain-Sloped:</b>	Typically
<b>Comments:</b>	Each building typically has 21-50 housing unit(s). 40-50 units in each building. Since the number of stories vary, a unique number

## Features

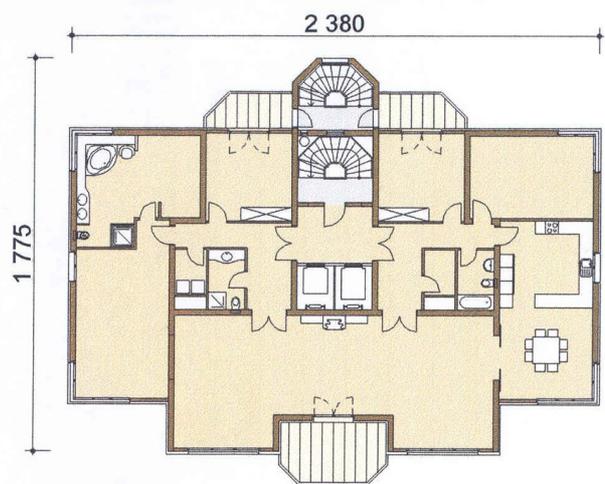
<b>Plan Shape</b>	Other
<b>Additional comments on plan shape</b>	The buildings enjoy a wide variety of plan and elevation shapes.
<b>Typical plan length (meters)</b>	10-30
<b>Typical plan width (meters)</b>	10-30
<b>Typical story height (meters)</b>	2.8
<b>Type of Structural System</b>	Structural Concrete: Structural Wall: Moment frame with in-situ shear walls
<b>Additional comments on structural system</b>	The vertical load-resisting system is reinforced concrete structural walls (with frame). The walls and the slab carry all gravity loads. Gravity loads are transferred uniformly to the walls by slabs. A mat foundation is commonly used to transmit the gravity loads to the soil. The lateral load-resisting system is reinforced concrete structural walls (with frame). Structural walls provide the lateral-load resistance. The walls and the slab are cast in a single operation using specially designed half-tunnel-steel forms (upside down U shape) that maintains a certain size as shown in Figures 8 and 9. This cuts down the construction time significantly. The wall and the slab form a monolithic joint. The following construction sequence is implemented. 1) The tunnel forms are first cleaned and coated with form oil. Then they are placed in their positions by using the kicker as the guide (Figures 8 and 9). 2) The wall reinforcement is placed before the tunnel formwork is positioned. Reinforcement steel and electric

	<p>conduits are set in their places on the tunnel form (Figure 9). 3) Walls, slab and kickers are cast. The next morning the formwork is ready to be stripped and carried to the next location by a crane. In accordance with the design, steel blockouts may be installed on the formwork panels to form the plumbing openings. Figures 10 and 11 show the elevation and plan of a typical building constructed by this technique. Figures 12 to 15 show samples of the reinforcement detailing and the structural drawings taken from the blueprints of a typical building.</p>
<b>Gravity load-bearing &amp; lateral load-resisting systems</b>	
<b>Typical wall densities in direction 1</b>	5-10%
<b>Typical wall densities in direction 2</b>	5-10%
<b>Additional comments on typical wall densities</b>	<p>The typical structural wall density is up to 10%. 2% - 6% The typical density of structural walls is about 4 percent of the area of one floor. This density may vary from 2 to 6 percent depending on the thickness of the wall, the span and the plan dimensions of the building. Both principal directions usually have the same density.</p>
<b>Wall Openings</b>	<p>The construction sequence creates walls and floor slabs typically without openings during the primary concrete placement. Windows looking outside and interior doors or partitions are usually crafted from precast panels or lightweight concrete blocks. When architectural form allows it, doors may also be formed by leaving openings in the formwork during the primary casting.</p>
<b>Is it typical for buildings of this type to have common walls with adjacent buildings?</b>	No
<b>Modifications of buildings</b>	The peculiar construction technique does not allow any structural modifications to the building.
<b>Type of Foundation</b>	<p>Shallow Foundation: Mat foundation  Deep Foundation: Reinforced concrete bearing piles  Deep Foundation: Reinforced concrete skin friction piles</p>
<b>Additional comments on foundation</b>	It consists of reinforced concrete end-bearing piles and reinforced concrete skin-friction piles.

<b>Type of Floor System</b>	Cast-in-place beamless reinforced concrete floor Other floor system
<b>Additional comments on floor system</b>	
<b>Type of Roof System</b>	Cast-in-place beamless reinforced concrete roof Roof system, other
<b>Additional comments on roof system</b>	
<b>Additional comments section 2</b>	The Turkish Building Development Law requires a minimum separation distance of 6 m for detached buildings. Tunnel form buildings are usually in the 12-16 story range, so the space between them is converted into common lawns by developers, and the buildings have substantial separation distances between. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.



***Selected Plan Configuration-1***



***Selected Plan Configuration-2***

## **Building Materials and Construction Process**

### **Description of Building Materials**

<b>Structural Element</b>	<b>Building Material (s)</b>	<b>Comment (s)</b>
Wall/Frame	Concrete Reinforcing Steel	25 MPa/ 500 MPa
Foundations	Concrete Reinforcing	25 MPa/ 500 MPa

	Steel	
Floors	Concrete Reinforcing Steel	25 MPa/ 500 MPa
Roof	Concrete Reinforcing Steel	25 MPa/ 500 MPa
Other		

## Design Process

<b>Who is involved with the design process?</b>	EngineerArchitect
<b>Roles of those involved in the design process</b>	
<b>Expertise of those involved in the design process</b>	Turkish contractors have gained much experience with tunnel form building construction, and have successfully applied this experience in many cases for foreign contracts, e.g. in Russia, North Africa, Caucasias and the MiddleEast. Although formal engineering registration does not exist in Turkey, these buildings go through a strict design, check, and supervision process.

## Construction Process

<b>Who typically builds this construction type?</b>	Contractor
<b>Roles of those involved in the building process</b>	The construction of this type requires certain capacities the large construction companies have, thus it is typically build by experienced developers.
<b>Expertise of those involved in building process</b>	Turkish contractors have gained much experience with tunnel form building construction, and have successfully applied this experience in many cases for foreign contracts, e.g. in Russia, North Africa, Caucasias and the MiddleEast. Although formal engineering registration does not exist in Turkey, these buildings go through a strict design, check, and supervision process.
<b>Construction process and phasing</b>	See Structural Features. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. The tunnel form buildings are built in one construction cycle, and no increments or modifications are possible at a later stage.
<b>Construction issues</b>	

## Building Codes and Standards

<b>Is this construction type address by codes/standards?</b>	Yes
<b>Applicable codes or standards</b>	<p>This construction type is addressed by the codes/standards of the country. 1. Regulations for Buildings to Be Built in Disaster Areas (1998) 2. TS 500: Requirements for Design and Construction of Reinforced Concrete Structures(2000). The year the first code/standard addressing this type of construction issued was The seismic requirements have been first issued in 1945. The first edition of TS 500 was in 1969. We refer to Contribution No. 64 for a detailed account of the development of building codes and standards in Turkey. Most material codes have been issued by the Turkish Standards Institute at different dates. The most recent code/standard addressing this construction type issued was 1. The seismic requirements have been last issued in 1998. 2. The last issue of TS 500 is dated 2000.</p>
<b>Process for building code enforcement</b>	<p>Developer submits designs and other required documents to the relevant local government to receive the construction permit.</p>

## Building Permits and Development Control Rules

<b>Are building permits required?</b>	Yes
<b>Is this typically informal construction?</b>	No
<b>Is this construction typically authorized as per development control rules?</b>	Yes
<b>Additional comments on building permits and development control rules</b>	

## Building Maintenance and Condition

<b>Typical problems associated with this type of construction</b>	
<b>Who typically maintains</b>	

**who typically maintains buildings of this type?**

BuilderOwner(s)Renter(s)

**Additional comments on maintenance and building condition**

## **Construction Economics**

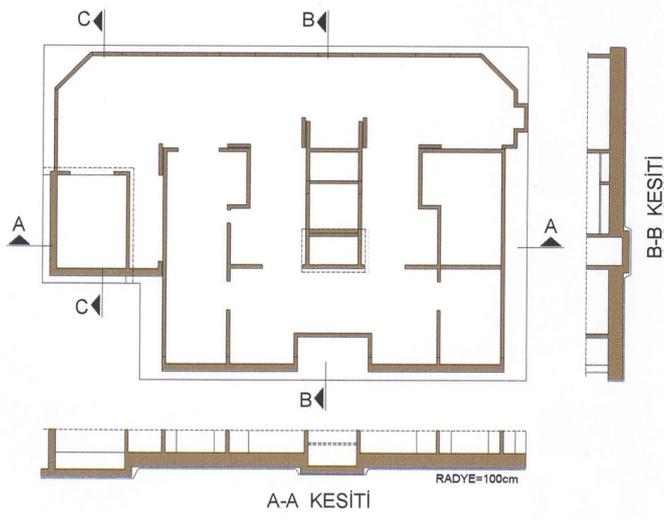
**Unit construction cost**

The average estimated unit construction cost for post-earthquake housing including utilities but excluding land is \$154/m<sup>2</sup>. This usually corresponds to \$ 15 000 per housing unit. The approximate cost for the utilities is \$30/m<sup>2</sup>. The total cost of a housing unit including land strongly depends on the location and its architectural finish. One of the main advantages of this construction type is the speedy construction process. The formworks are handled by cranes and the ready mix concrete use minimizes the labor dependency. The cost efficiency is gained by optimizing labor, using less concrete, and minimizing the finishing work. This construction technique greatly reduces construction time by as much as 50% and the costs by 20 percent relative to the conventional methods. It may take up to one year for the construction of a typical building to be completed.

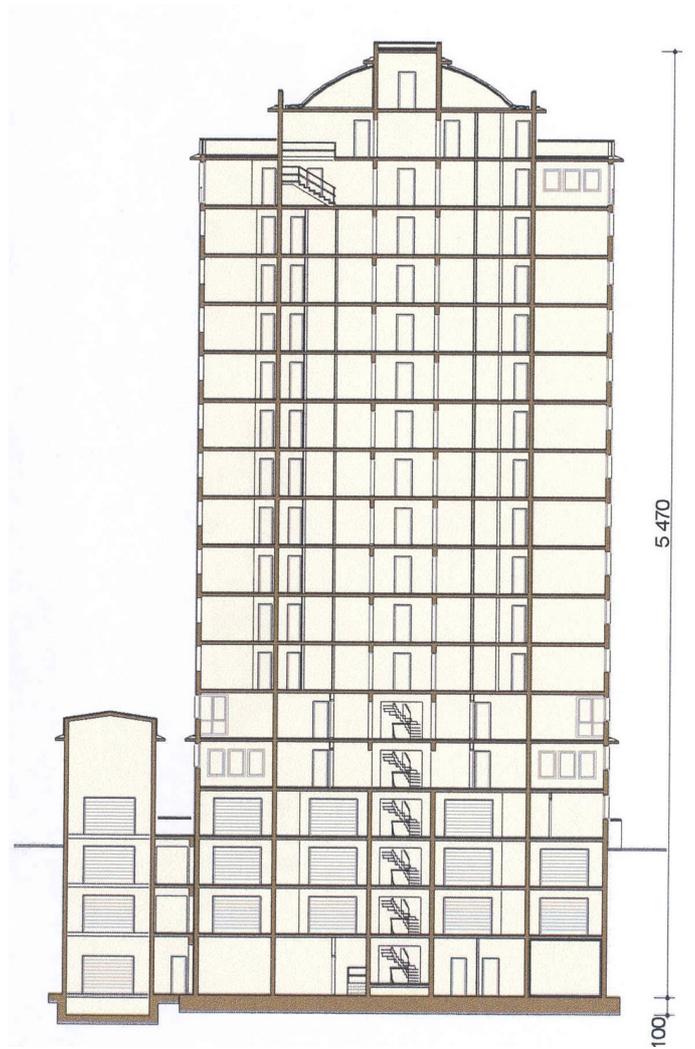
**Labor requirements**

**Additional comments section 3**

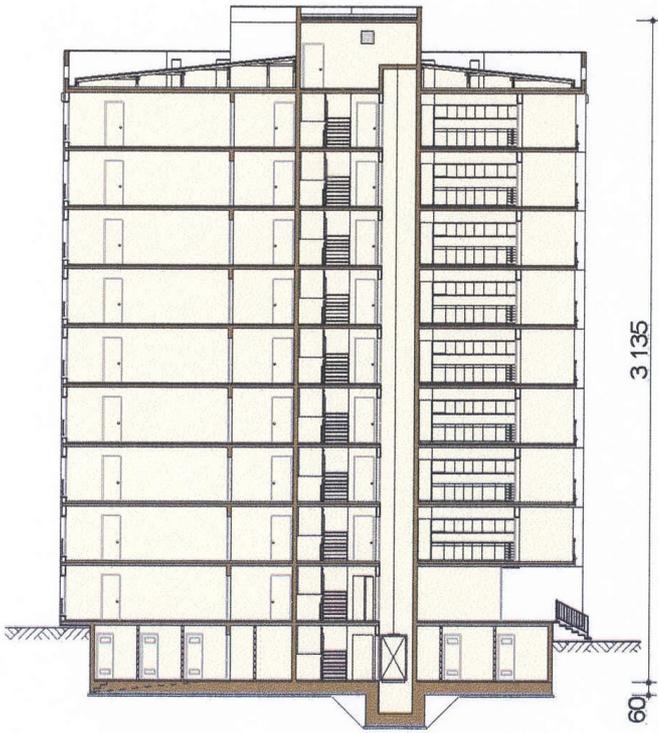
There is currently no specific set of requirements for this construction type in the current seismic design code. The walls are designed and detailed according to the specifications for reinforced concrete walls. Therefore, the choice of strength reduction factor,  $R$ , depends on the preference of the design engineer and the contractor for the building at hand. In general, a value between 4 to 6 is used by considering the economy. The high value requires more restrictive detailing requirements and wall thicknesses that lead to a trade-off rating between speed of construction and cost.



***Selected Plan Structural Configuration-1***



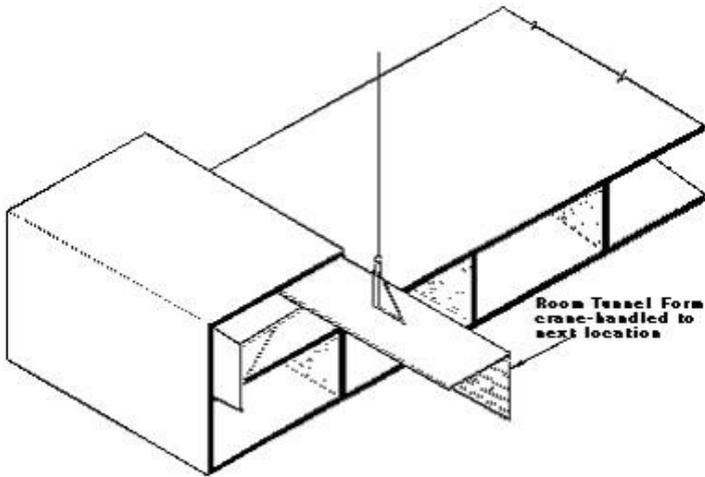
***Selected Elevation Configuration-1***



***Selected Elevation Configuration-2***



***Selected Elevation Configuration-3***



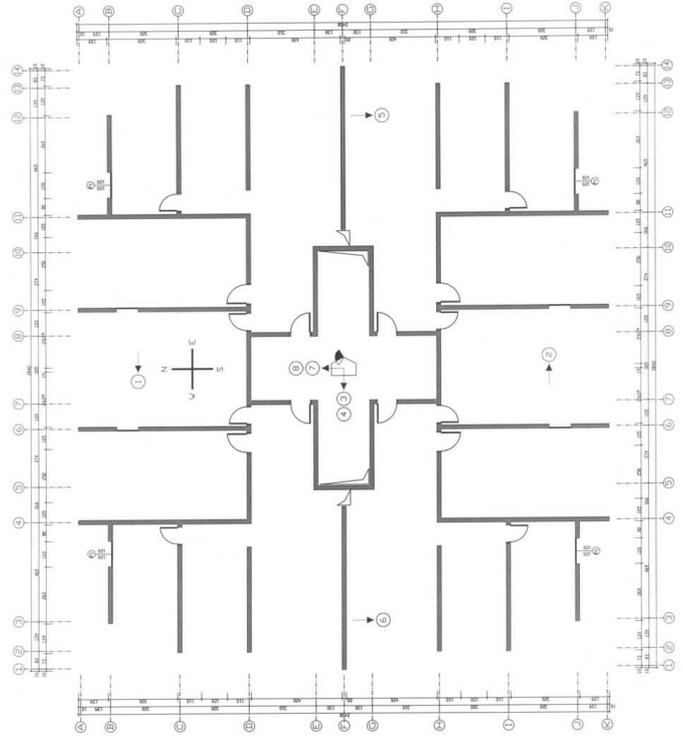
***Half-Tunnel Forms Handled by Cranes***



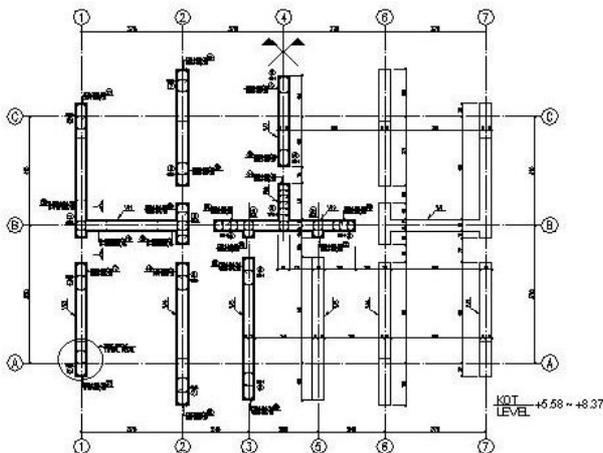
***Reinforcement Details for Walls with and without Openings***



**A Typical Tunnel Form Building Nearing Completion (Note Masonry Facade Elements)**

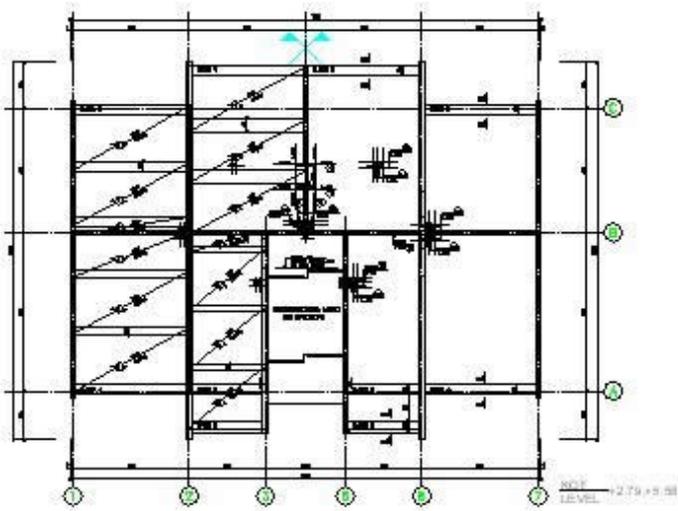


**Structural Plan of the Building in Figure 10 (Building Footprint Measures 25x27m, and Its Height is 25m)**

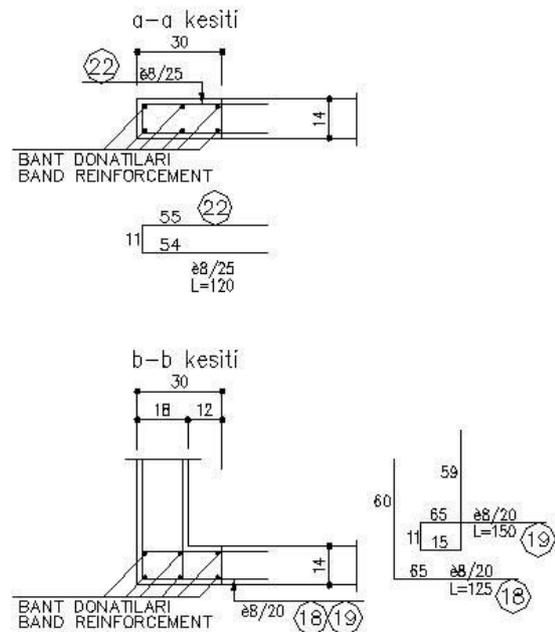


**The Structural Plan of a Typical Floor**

**The Structural Plan of a Typical Floor Reinforcement Detailing for a Wall Section Extracted from the Plan Given in Figure 12**



**Drawing for the Reinforcement Detailing of a Typical Floor**



**Strip Reinforcement for Section a-a of Figure 14**

## Socio-Economic Issues

<p><b>Patterns of occupancy</b></p>	<p>Nearly all occupants are single family or co-family. Each building typically has 40-50 housing unit(s). Since the number of stories vary, a unique number for the units in a building is hard to assign. Typically there are four apartment units per floor and average number of floors is 10-12.</p>
<p><b>Number of inhabitants in a typical building of this construction type during the day</b></p>	<p>&gt;20</p>
<p><b>Number of inhabitants in a typical building of this construction type during the evening/night</b></p>	<p>&gt;20</p>
<p><b>Additional comments on number of inhabitants</b></p>	<p>The average size of a family residing in a unit of this type of construction is about 4. During the day, one or two inhabitants reside in their units.</p>
<p><b>Economic level of inhabitants</b></p>	<p>Middle-income class High-income class (rich)</p>
<p><b>Additional comments on economic level of</b></p>	<p>Economical level of inhabitants depends strongly on the address of the building which also influences the price of the house unit. In Turkey, there is probably a poor correlation between the income and the price</p>

<p><b>Economic level of inhabitants</b></p>	<p>of the house unitpeople own. Economic Level: The ratio of price of each housing unit to the annual income can be 6:1 for middle classand 3:1 for rich class families.</p>
<p><b>Typical Source of Financing</b></p>	<p>Owner financedPersonal savingsInformal network: friends or relativesInvestment poolsOther</p>
<p><b>Additional comments on financing</b></p>	<p>A number of successful developers have constructed multi-family housing of this type during the last quarter century.The way it works is as follows: Families wishing to invest in a dwelling unit enter a private contract with thedeveloping company that sets the conditions for the payments and delivery dates. Well managed enterprises haveenabled tens of thousands of families to have their own house. Another scheme is for prospective homeowners toform a cooperative whose state of objective is to built multi-unit family housing. In this, families must typicallyfinance about half of the cost of the finished building with the remainder coming from the government housingadministration, a government housing financing scheme that was created in 1984 to address the housing shortage inthe country. Many of the 1.1 million housing units constructed during 1984-2001 were financed by the housingadministration.</p>
<p><b>Type of Ownership</b></p>	<p>RentOwn outrightUnits owned individually (condominium)</p>
<p><b>Additional comments on ownership</b></p>	
<p><b>Is earthquake insurance for this construction type typically available?</b></p>	<p>Yes</p>
<p><b>What does earthquake insurance typically cover/cost</b></p>	<p>Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildingsor new buildings incorporating seismically resilient features, an insurance premium discount or more completecoverage is unavailable. DASK, a recently established entity similar to California Earthquake Authority, providesmandatory country-wide insurance for all property up to a ceiling of \$40,000. For amounts in excess of this ownersmust purchase voluntary insurance. Although this construction type has an excellent earthquake performance, thecurrent earthquake insurance coverage treats all concrete structures under the same category when determining thepremiums. DASK employs three classifications for the construction type, namely concrete</p>

structures, steel structures and masonry buildings. A second factor that is taken into account when determining premiums is the seismic region (based on current seismic zone map) in which the building resides. Work is underway to establish a more refined tariff structure. Insurance provided by DASK covers structure only. In high-hazard areas a dwelling of the type described under this section will have an annual premium of some \$40-50.

<b>Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?</b>	No
<b>Additional comments on premium discounts</b>	
<b>Additional comments section 4</b>	

## Earthquakes

### Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1999	Izmit, Turkey
2003	Bingol, Turkey

### Past Earthquakes

<b>Damage patterns</b>	This construction type has experienced the two major earthquakes of 1999 and the earthquake of 2003. Neither demolished nor damaged buildings of this type have been reported after these earthquakes. Figures 16-20 demonstrate the conditions of several buildings after these earthquakes. Several buildings surviving the earthquakes of 1999 are shown in Figures 16-18.
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**observed in past earthquakes for this construction type**

The building in Figure 16, that is virtually untouched, is located 3-4 km from the fault that was ruptured during the earthquake. In the city of Bingle, although extensive damage was observed in reinforced concrete frame structures, a group of five story tunnel from buildings (Figure 19) performed superbly without any sign of structural damage. Only minor nonstructural damage in the form of separation of the precast panels from the floors was observed.

**Additional comments on earthquake damage patterns**

Facade elements are usually pre-cast reinforced concrete panels that are placed after the walls have been formed, and attached along their periphery by welding. These have been observed to exhibit minor separation or cracking along their boundary, but this is not considered to be a structural deficiency. The spandrel beams above the door openings have been observed to suffer shear cracks. This does not lead to a reduced seismic capacity of the system therefore is considered as minor damage.

**Structural and Architectural Features for Seismic Resistance**

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than 1/2 of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.

<b>Structural/Architectural Feature</b>	<b>Statement</b>	<b>Seismic Resistance</b>
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE

Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at	FALSE

each diaphragm level with metal anchors or straps.

Wall Openings		N/A
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	TRUE

## Building Irregularities

<b>Additional comments on structural and architectural features for seismic resistance</b>	The concrete strength is typically 25 MPa, which is well above average concrete strength encountered in the country.
<b>Vertical irregularities typically found in this construction type</b>	Other
<b>Horizontal irregularities typically found in this construction type</b>	Other
<b>Seismic deficiency in walls</b>	
<b>Earthquake-resilient features in walls</b>	The walls being the primary load-carrying members are proven to be the most effective members against earthquakes. Wall density helps in reducing the unit shear, and enables almost elastic response during even strong ground shaking.

Spandrel beams formed above door openings have

**Seismic deficiency in frames**

been observed to experience cracks when the building is subjected to strong seismic action. This is of little structural significance.

**Earthquake-resilient features in frame**

**Seismic deficiency in roof and floors**

**Earthquake resilient features in roof and floors**

The honey-comb pattern of walls and slabs enables slabs to respond in their elastic range.

**Seismic deficiency in foundation**

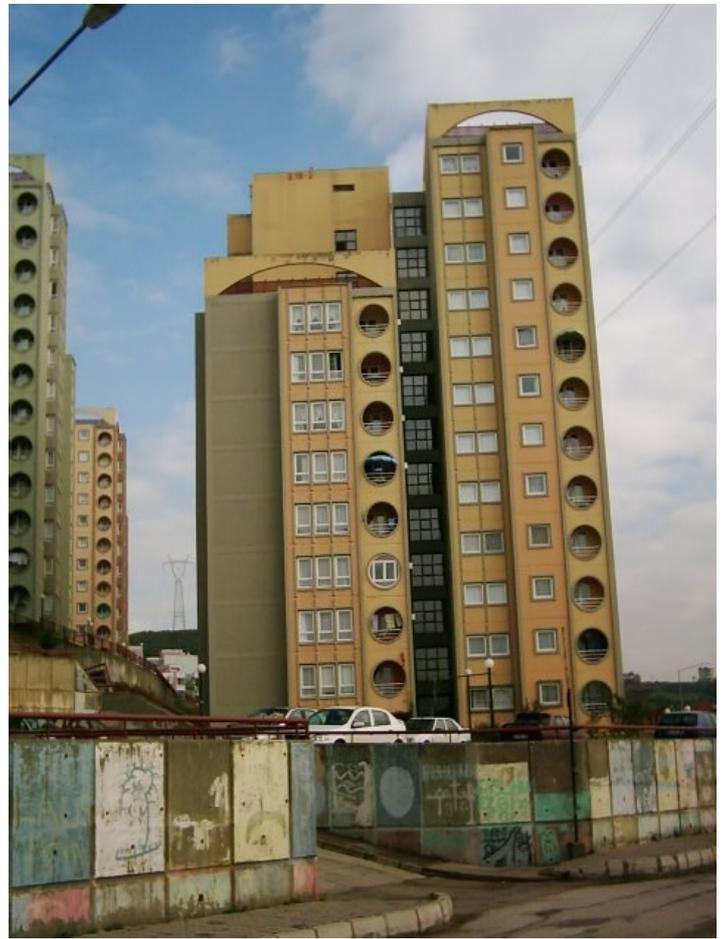
**Earthquake-resilient features in foundation**

**Seismic Vulnerability Rating**

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines](#)

	<b>High vulnerability</b>		<b>Medium vulnerability</b>		<b>Low vulnerability</b>	
	A	B	C	D	E	F
Seismic vulnerability class						0

□ ***The Building Is Part of a Multi-unit Housing Complex That Survived the Earthquakes of 1999 in Izmit without Damage***



***The Post-Earthquake Condition of Another Tunnel Form Building of a Different Housing Complex in Izmit***



***This Tunnel Form Building Located in Bekirpasa/Izmit Also Suffered No Damage during the Earthquakes in 1999***

□ ***Tunnel Form Buildings after the Bingol Earthquake of May 1, 2003***

**Retrofit Information**

## Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Shear cracks in spandrel beams.	Epoxy injection.
<b>Additional comments on seismic strengthening provisions</b>	Since no reported cases of significant damage have been encountered for this construction type, there are no widely experimented techniques of retrofitting developed and used for this construction type.
<b>Has seismic strengthening described in the above table been performed?</b>	The minor damage observed in the spandrel beams is generally accounted for in the design phase thus is repaired by epoxy injection.
<b>Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?</b>	Not applicable.
<b>Was the construction inspected in the same manner as new construction?</b>	Not applicable.
<b>Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?</b>	Not applicable.
<b>What has been the performance of retrofitted buildings of this type in subsequent earthquakes?</b>	Not applicable.
<b>Additional comments section 6</b>	

□ ***A Practically Unscathed Building Subjected to the Bingol Earthquake***

## **References**

MESA Construction Co. website, [www.mesaimalat.com.tr](http://www.mesaimalat.com.tr)

Turkish Government Housing Administration website, [www.toki.gov.tr](http://www.toki.gov.tr)

MESA Imalat, personal communicationAkt

Turkish Prime Ministry, Project Implementation Unit, personal communicationKahraman,M.

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