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Structural Challenges with the SOCAR Tower in Baku, a New Megacity in the Caspian Region

巴库SOCAR大厦中的结构挑战 —— 一座里海地区的新兴大都市

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Hyungsup早年在高层建筑房屋设计领域有着知名影响力的SOM纽约公司任职，是公司主管，参与了纽约在线华纳时代中心和韩国乐天超级塔项目。他在美国纽约公司工作13年之后于2009年回到了韩国并成为韩国最大建筑师事务所之一的Heerim公司的高级副董事长，并在各大项目中持续推动技术革新，如韩国Busan的乐天塔项目、阿塞拜疆巴库的新月酒店项目、韩国CJ Only One R&D中心项目。

Abstract | 摘要

Baku, the capital of Azerbaijan, has been rapidly transforming into a hub of high-rise buildings and cultural centers in the Caspian region. Baku's population now accounts for more than 40 percent of the nation. With the 2012 opening of the new Heydar Aliyev International Airport, the city skyline has been reshaped by tall buildings; among these, the SOCAR Headquarters Tower is the tallest. The SOCAR Tower posed many structural challenges due to its location in the seismically active Absheron Peninsula – similar to the West Coast of the US. This name of this area in Baku means "wind-pounded city," as the wind loads are high, like the Alaskan coastal region. There was confusion about which design criteria/codes to apply to new high-rise projects in Baku before the Azerbaijan Seismic Building Code was published in 2010. This paper details the general structural design approaches used for the SOCAR Tower, as well as the optimization of the superstructure and foundation system.

Keywords: New Hub, Seismically Active, Structural Challenges, Transforming and Wind-pounded

巴库，阿塞拜疆共和国的首都，正迅速地转变为一个里海地区新的摩天大厦之都和活跃的文化中心。 如今巴库的人口超过国家总人口数的40%，因此她需要更多的建筑来满足快速增长的对住宅和商务的需求。随着2012年Heydar Aliyev巴库国际机场的开放，全新的高层建筑群完全重塑了城市的天际线。当中，SOCAR总部大厦是最高的。 高达200.45米的SOCAR大厦由于坐落在相当于美国西海岸的Absheron半岛活跃地震带，这对结构设计提出了相当多的挑战。 另外，正如城市名"巴库"之意"被暴风捶打之城"，设计风荷载很高，近似于在阿拉斯加海岸地区。 直至"阿塞拜疆抗震建筑规范"于2010年出台之前，如何选用合适的设计准则和规范一直都困扰着巴库新兴的高层建筑项目。此论文包含了用于火焰形SOCAR大厦的总体结构设计方法和对上部结构和基础系统的优化。

关键词：新中心、地震活跃、结构挑战、转变、狂风拍打

Geographical Significance of SOCAR Tower

SOCAR Tower (Figure 1) is located on Heydar Aliyev Avenue – to be referred to as "The Ave" hereafter – which was named after the former president of the Republic of Azerbaijan. The Ave is geographically important, as it connects Heydar Aliyev Baku International Airport with the new central districts of the Downtown Baku area, as well as the old city. The Ave is also politically important, as it provides the first impression for all foreigners when they enter the country. The Ave was about 5.6 kilometers long and used to be narrow, hemmed in by low-rise masonry residential structures built during the Soviet occupation. Major infrastructure upgrades and architectural transformations have been made along the Ave in recent decades, including widening to 10 lanes (a six-lane highway and four-lane local roads); renovating and refinishing existing residential buildings with the locally available limestone; and the construction of new modern buildings, including notable

SOCAR大厦显著的地理位置

SOCAR大厦（图1）坐落于以阿塞拜疆共和国前总统的名字所命名的Heydar Aliyev （阿里耶夫）大道。这条大道贯通了Heydar Aliyev巴库国际机场和新建的巴库市中心，还有老城区，所以在地理位置上格外的重要。同时，这条大道也为飞抵巴库的外国人留下了对这个国家的第一印象，所以具有特殊的政治意义。大道长约5.6公里，曾经是一条狭窄的、被苏联时期建造的低层砌块住宅建筑所包围的道路。在过去的数十年里，这里进行了一系列的基础设施升级和建筑房屋的改造，道路被扩建为十车道（六条为高速车道，四条为区间车道），利用当地特有的大理石对现有居民建筑进行改建和翻新，新建的现代化大厦也在此拔地而起，其中包括：Heydar Aliyev文化中心（扎哈·哈迪德设计）、巴库国家体育场、国家体操竞技场、SOFAZ大厦、Azinko大厦、巴库大厦、Azersu大厦和SOCAR大厦（图2）。其中，SOCAR大厦是这条大道上最大型的高层办公楼。

Figure 1. SOCAR Tower (Source: Heerim Architects & Planners)
图1. SOCAR大厦外观图片（来源：Heerim Architects & Planners）

structures such as Heydar Aliyev Cultural Center (designed by Zaha Hadid), Baku National Stadium, National Gymnastics Arena, SOFAZ Tower, Azinko Tower, Baku Tower, Property Tower, Azersu Tower, and SOCAR Tower (Figure 2). Among the above mentioned towers, SOCAR Tower is the largest office tower development along the Ave.

Project Brief

The State Oil Company of the Azerbaijan Republic – "SOCAR" hereafter – is, as the name depicts, a state-owned national oil company headquartered in Baku, Azerbaijan. SOCAR produces oil and natural gas from onshore and offshore fields in the Azerbaijani section of the Caspian Sea. It is one of the largest fossil fuel corporations in the world. With successful business growth, management decided to build a new office on the Ave in order to accommodate an increasing number of employees (Heydar Aliyev Foundation 2007). The design of the new SOCAR Tower began in September of 2007 with the architecture firm, Heerim Architects & Planners – "Heerim" hereafter – based in Korea. Thornton Tomasetti's New York office was involved in the schematic and design development phases of the project as a structural engineer, and re-engaged in the project to support Heerim and Tekfen Construction and Installation – "Tekfen" hereafter – companies during the construction administration phase. The SOCAR Tower is a 38-story office tower with a gross floor area of approximately100,000 square meters. The

Figure 2. Recent tower development along Heydar Aliyev Avenue (Source: Heerim Architects & Planners)
图2. 近期Heydar Aliyev大道周边的大楼建设（来源：Heerim Architects & Planners）

项目简介

阿塞拜疆共和国国家石油公司（下文简称"SOCAR"）正如名字所写，是一家总部设在巴库的国有公司。SOCAR自里海阿塞拜疆区域的内陆及近海生产石油和天然气，是世界上最大的化石燃料公司之一。借由成功的商业发展，管理层决定在大道上新建一栋办公楼以应对逐渐增长的员工数量（Heydar Aliyev 基金会，2007年）。全新的SOCAR大厦的建筑设计始于2007年9月，由韩国的Heerim Architects & Planners公司（下文简称"Heerim"）担纲。Thornton Tomasetti 纽约办公室作为结构工程师参与了方案设计和扩初设计阶段，并为Heerim和Tekfen Construction and Installation 公司（下文简称"Tekfen"）在施工管理阶段提供了支持。SOCAR大厦是一栋38层办公楼，总建筑面积约10万平方米。大厦提供A级办公场所、客房、会议室、及配备健身中心和商铺的空中休憩厅，再加上充足的地下停车库用以满足员工和访客的泊车需求。此外还有独立的三层设施裙房结构，裙房由位于SOCAR大厦底部的人行天桥与主塔相连。裙楼包含了会议室和各种便利设施如餐厅、咖啡厅、商业街和健身俱乐部。当2014年末封顶时，SOCAR大厦成为了国内最高的建筑，其内部装潢于2015年8月完成（图3）。

建筑设计主题和设计过程

SOCAR大厦的灵感来自于火、风和能量的图案，其分别代表阿塞拜疆、巴库和SOCAR。跃动的火焰燃烧图案代表着国家持续的发展和未来。火是由空气（风）、燃料和热能反应而产生的，三者构成了不停燃烧所需的"能量三角"，其代表了能量流或者能量的喷发。

空间的横向规划正迎合此概念，寓意着冲破束缚的能量将要旋转着着纵向喷发，这也成就了大厦的基本外形。

为了突出大厦标志性的火、风、能量的形态特征，除去一座在二楼的桥梁和地底通道外，主楼和裙楼是完全分离的。从主楼通往裙楼的通道以地上景观设计的形式呈现。

结构体系和设计准则

38层办公用塔楼由位于中央的混凝土核心筒及环绕核心筒的组合钢框架楼板和钢柱组成。双重抗侧向力体系包括：一、设计来抵抗地震下超大塑性变形的特殊加固混凝土核心筒和；二、外围钢结构特殊框架（图4）。此项目按典型高层结构进行设计，考虑了包括限制风荷载下结构加速度值以保障居住舒适度、风荷载和地震荷载下结构位移，和一定程度的富余度。此结构设计为风荷载工况控制，所以在塔顶安装了调频质量阻尼器以减小结构加速度值，提高了塔楼的舒适度。

结构设计依据了参考美国规范ASCE 7–05的国际建筑规范（IBC 2006）。应用的设计规范包括：美国混凝土协会《结构混凝土建筑规范ACI 318–05》；美国钢结构建造协会《设计手册LRFD 第13版》,(美国混凝土协会2005)。

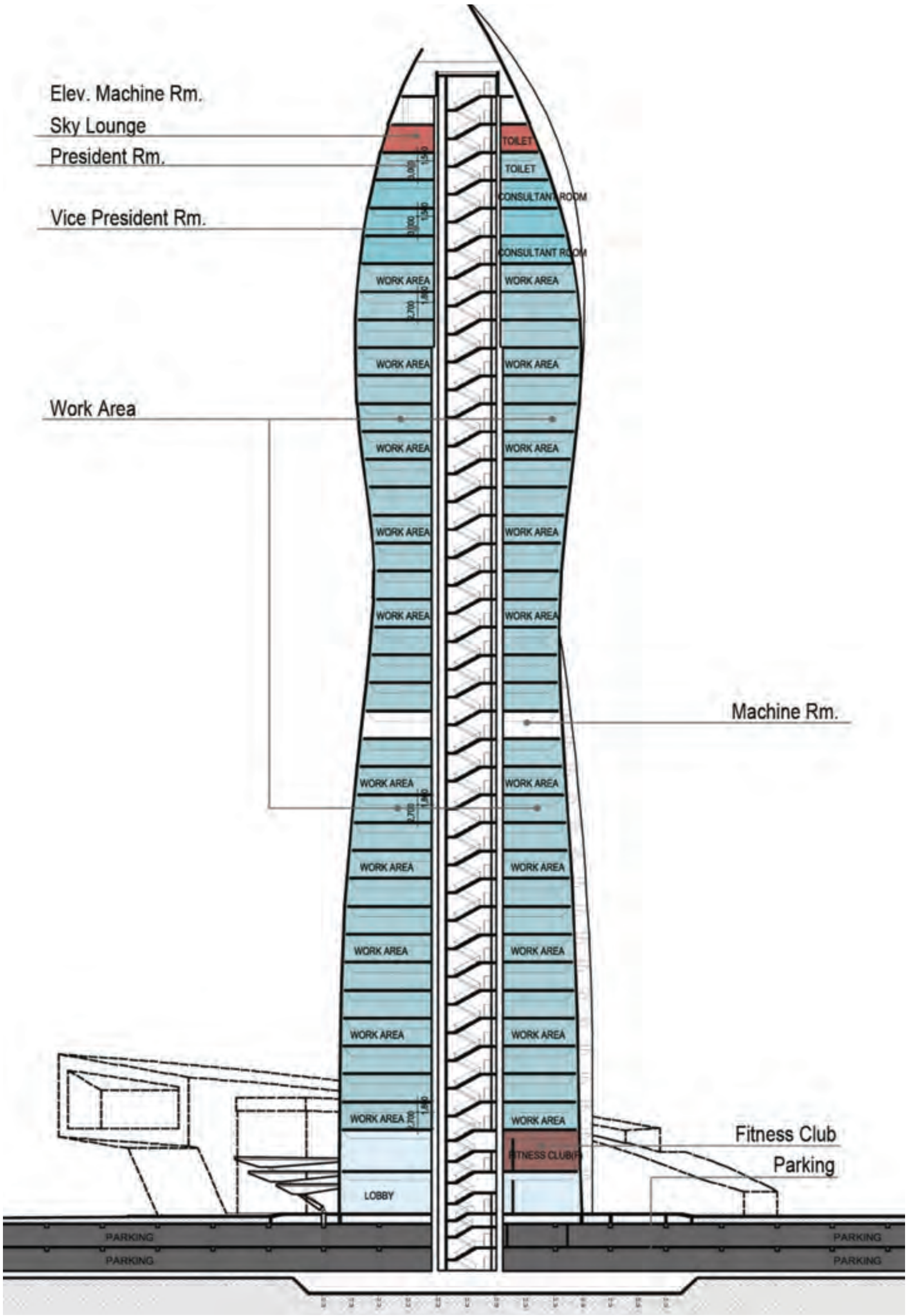

Figure 3. Tower zoning planning (Source: Heerim Architects & Planners)
图3. 大厦分区规划（来源：Heerim Architects & Planners）

tower provides Class-A office space, guest houses, conference rooms, a sky-lounge with amenities such as fitness centers, and retail, plus sufficient underground parking to accommodate employees and visitors. There is a separate three-story amenity podium structure connected to the SOCAR Tower by a pedestrian bridge at the tower base. The podium consists of conference rooms and amenity spaces, such as restaurants, a cafeteria, retail, and a fitness club. The SOCAR Tower became the tallest tower in the country when the structure was topped out in late 2014 and the interior fit-out was completed in August of 2015 (Figure 3).

Architectural Design Motives and Process

SOCAR Tower is inspired by the motifs of fire, wind, and energy, which represent Azerbaijan, Baku, and SOCAR, respectively. The dynamically burning image of fire represents continuous development of the country and its future. Fire is generated from the reaction of air (wind), fuel, and heat, which together form the "energy triangle" needed for continuous combustion, representing the flow or eruption of energy. The spatial arrangement of the horizontal program drew upon this concept, imagining energy that surpassed the limit of the program becoming a vertical eruption with a rotation that became the basic form of the Tower.

To highlight the symbolic form of the Tower, drawn upon the ideas of fire, wind, and energy,

结构材料

塔楼结构为一种由钢筋混凝土核心筒与钢结构组合楼板和钢柱组成的混合结构。混凝土强度等级最大不超过C50（f’c = 50 MPa）。因此，下部楼层的核心筒墙体和连梁混凝土强度采用了C50而上部楼层采用了C40（f’c = 40 MPa）。浇筑在压型钢板上的混凝土楼板采用C30（f’c = 30 MPa）混凝土。外围框架采用了屈服强度为345MPa的高强结构钢。两层地下室采用了C30现浇钢筋混凝土结构，筏板使用了C35（f’c = 35 MPa）混凝土。

楼盖体系

塔楼和群楼的典型楼盖使用了组合型钢梁支撑的94mm厚混凝土浇筑于46mm厚压型钢板之上。深410mm中心间距为3米的钢次梁与楼板共同作用。H型钢柱和外框梁刚接，形成外围框架作为抗侧向力体系一部分（图5）。地下室楼盖采用了200mm厚单向混凝土楼板，其次梁间距约为2.85米。

行走激励造成的典型楼盖震动根据AISC Design Guide 11进行了校核，在该指导手册中最大楼板加速度值设为5 milli-g。TT被告知各层办公区将安装架空地板和全楼高的隔墙，基于此条件可采用4%~5%的楼板阻尼比，楼板震动将会在可接受的范围内（AISC Design Guide 11-1997 2009）。

塔楼外围复杂的几何形状要求结构工程师绘制每一楼层平面平面图来体现各个楼层的巨大变化。通过与幕墙系统相平行的斜柱，楼层平面间的转换才得以实现（图6）。每当柱子斜率在楼层面处改变的时候，水平力由浇筑于压型钢板之上的混凝土组合楼板承担。额外的剪力连接件用来保证钢梁与上部楼板之间的传力途径。在与核心筒交界处的楼板内布置锚筋和集力钢筋，保证水平力被传导至核心筒中。

风和地震荷载

如前文所述，巴库之名源于强风。因为此前设计时并没有可靠的数据用来计算巴库地区结构设计风荷载，所以一开始结构工程师被要求使用基于SNiP code 2.01.07-89规范的均匀的使用水准风压（6kPa, 120psf）。随后，风洞顾问参与到项目当中并协助结构工程师对风荷载进行了评估（图7）。依据风洞试验报告，当回归周期为50年和地面粗糙度类别为C类时，基本风速（10米水平面处的3秒阵风）为53米/秒。塔楼的重要性系数为1.0。风洞结果显示对该结构的设计风压非常大，近似于阿拉斯加海岸地区的风压。例如，其街

Figure 4. SOCAR Tower under construction (Source: Thornton Tomasetti, Inc.)
图4. 塔楼施工照片（来源：Thornton –Tomasetti，Inc.）

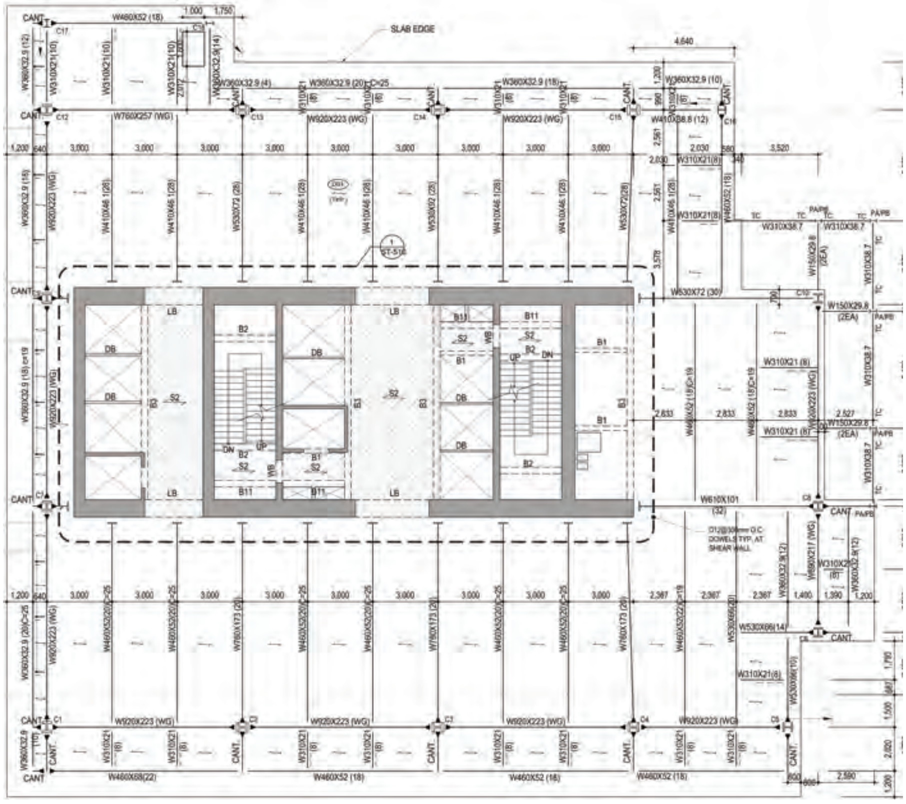

Figure 5. Typical floor framing plan (Source: Thornton Tomasetti, Inc.)
图5. 典型楼层构架平面图（来源：Thornton Tomasetti，Inc.）

it is kept physically separate from the podium, except for a bridge on the second floor and also by an underground connection. The connection from tower to podium is then expressed though landscape designs on the ground.

Structural System and Design Criteria

The 38-story office tower consists of a central concrete core surrounded by composite steel framed floors and columns. The dual lateral force resisting system includes a Special Reinforced Concrete Core detailed to resist significant in-elastic deformations under seismic events, together with perimeter steel Special Moment Frames (Figure 4). This project was designed with typical high-rise tower considerations including limiting building accelerations under wind for occupant comfort and building movement due to wind and seismic, and some level of redundancies. It is a wind controlled design, so a tuned mass damper was installed at the top of the tower to reduce building acceleration and to improve the serviceability of the tower.

The structural design was in accordance with the International Building Code (IBC 2006) that references ASCE 7-05. The applied design codes are the American Concrete Institute Building Code for Structural Concrete ACI-318-05 and the American Institute of Steel Construction Manual of Steel Construction, Load and Resistance Factor Design 13th edition (American Concrete Institute 2005).

Structural Materials

The tower is a hybrid structure consisting of reinforced concrete core walls with composite steel floor framing and columns. The concrete strength was limited to maximum C50 (f'c = 50 MPa); therefore, the core wall was constructed with C50 for the lower portion of core walls and link beams and C40 (f'c = 40 MPa) for the upper floors. Slabs were constructed with C30 (f'c = 30MPa) concrete fill on the metal deck. Framing uses high-strength structural steel with a yield strength of 345 MPa. Two basement levels are cast in place reinforced concrete structures with C30 concrete and the mat foundation used C35 (f'c = 35MPa) concrete.

Floor Framing System

Typical floor framing for the tower and podium uses composite steel beams supporting 94 millimeters of concrete fill over 46 millimeters of metal deck; 410-millimeter-deep infill beams typically spaced at three meters on center are designed composite with the slab. Wide flange columns and moment connected beams are used for the perimeter frames which are part of the lateral load resisting system (Figure 5).

道平面风压可达3kPa（60psf），大约是纽约市的三倍。

巴库位于Asheron半岛，在过去已经历过许多地震。地震荷载计算采用ASCE 7–05相关方法，并采用了当地专家组和地勘工程师提供的地震设计参数。某些参数（Ss=1.545g 和 S1=0.6g）基本与旧金山中心地区完全一样，这导致了最大设计反应谱加速度（Sds）等于1.03g。随后，对巴库地区数个施工场地进行的现场特定地面加速度研究显示，最大设计反应谱值较SOCAR大厦使用的假设值小约25%。如下面图8所示，由于风荷载工况产生的基地剪力和倾覆力矩大于地震荷载工况产生的，所以即便当初用于构件设计的地震荷载假定被高估了，也不会造成过于保守的塔楼设计。

抗侧体系设计

塔楼的抗侧向力系统是由特殊钢筋混凝土核心筒和特殊钢结构框架组成的双重体系。核心筒被设计为可在地震工况下承受巨大的塑性变形，与外围钢结构特殊框架共同工作（图9）。结构在东西方向的基本自振周期为4.71秒，在南北方向为2.84秒，扭转为1.39秒。塔楼的抗侧体系构件按满足巴库恶劣风象条件进行了设计；平面内矩形核心筒的剪力墙厚度由风作用在短方向（东西）上产生的变形控制，由于受结构几何形状的影响，外框架在该方向上的刚度很低。此抗侧体系设计满足了塔楼总体位移在风荷载下H/500的标准要

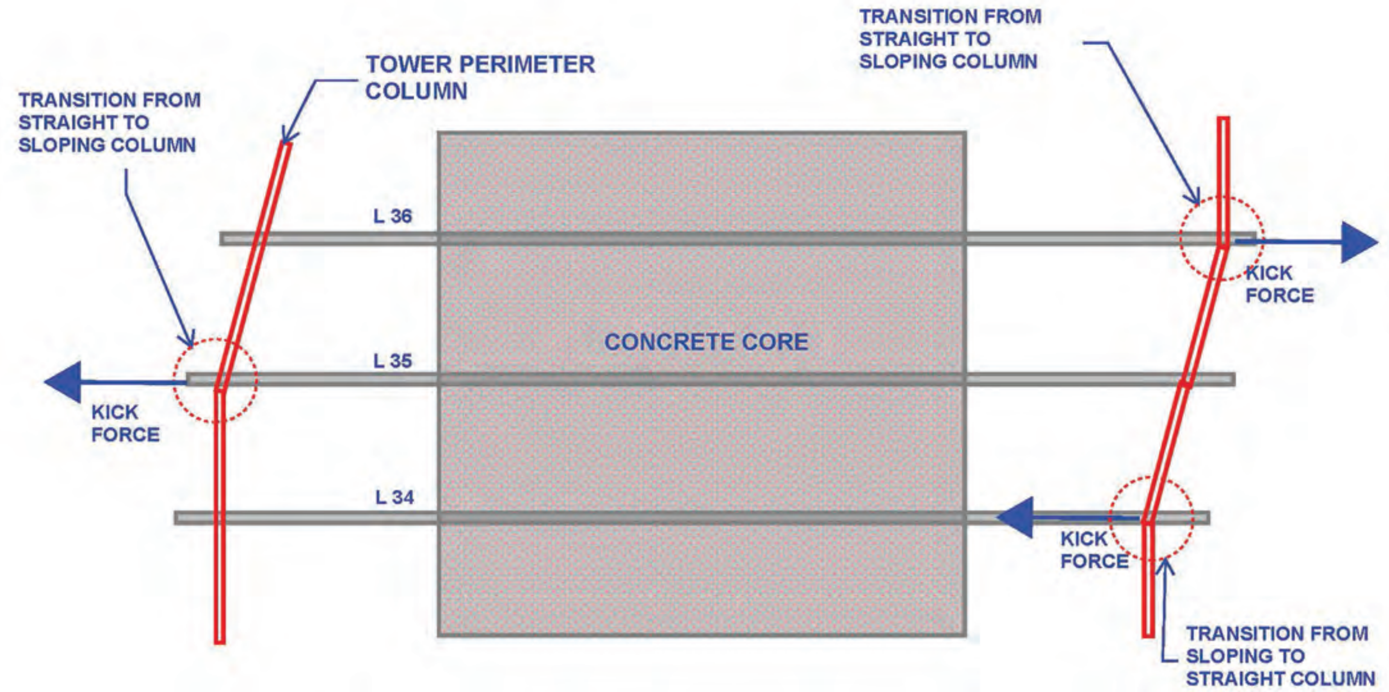

Figure 6. Tower section view of sloping column geometry (Source: Thornton Tomasetti, Inc.)
图6. 塔楼斜柱几何形状剖面详图（来源：Thornton Tomasetti, Inc.）

Basement floors have one way reinforced 200-millimeter concrete slabs on infill beams spaced at approximately 2.85 meters.

The vibration of typical floor framing due to walking excitations was checked with reference to the AISC Design Guide 11, which sets the maximum floor acceleration to five milli-g. TT was informed that raised floor would be provided and full partition walls are expected at the office. Based on this assumption and a floor damping ratio of four to five percent, the floor vibration appeared to be within an acceptable range (AISC Design Guide 11-1997 2009).

The complex geometry of the tower perimeter required the engineer to address plans with significant changes from floor to floor. Transitioning from one floor plan to another was achieved by sloping columns to be parallel with the curtain wall system (Figure 6). Where the column slope changes at a floor level, the horizontal resultant force – "kick force" – is resisted by the horizontal floor diaphragm of steel floor framing and concrete filled metal deck. Additional shear connectors (studs) were provided to ensure a load path from steel framing to concrete slab. The force is delivered to the core through dowels and collector reinforcement in the floor slab and at its interface with the wall.

Wind and Seismic Loads

As previously noted, Baku is named for its strong winds. Since there was no reliable data available for calculating the structural design wind loads in Baku at the time of the design, initially the structural engineer consultant was asked to apply a uniform service wind pressure of 6kPa (120 psf) based on SNiP code 2.01.07-89. Later, the wind tunnel consultant was engaged for the project and assisted the structural engineer consultant in estimating wind loads (Figure 7). According to the wind tunnel testing report, the basic wind speed (three-second gust at a 10-meter elevation) was 53 meters per second for a 50-year event, and wind exposure was C. The importance factor was 1.0 for the tower. The wind tunnel results showed that the design wind pressures for the structure were very large, similar to those in the coastal regions of Alaska. For

求。地震荷载产生的塑性层间位移角小于IBC规范（IBC 2010）对此0.020的限值。

核心筒剪力墙厚度在两个楼层处发生了改变：第6层从1000mm至800mm，第24层处从800mm至600mm。600mm厚的墙厚一直延伸到塔顶。核心筒剪力墙内的钢筋按抗震细部要求进行设计。依规范要求，在纵筋周围放置了密集的约束钢筋以防止混凝土在地震作用下发生脆性碎裂。核心筒剪力墙肢完全由连梁所整合在一起。由于尺寸限制，连结墙肢的连梁不是按交叉斜向配筋，而是按内埋型钢混凝土梁设计。当梁深被限制在1200mm时，连梁高宽比大于三，这使得交叉配筋的方案有效性降低。

Figure 7. Wind tunnel testing (Source: Rowan Williams Davies & Irwin Inc.)
图7. 风洞试验照片（来源：Rowan Williams Davies & Irwin Inc.）

example, the street level wind pressure was up to three kPa (60 psf) – approximately three times of that used in New York City.

Baku is located in the Peninsula of Asheron, which has witnessed many seismic events in the past. Seismic loads were calculated using ASCE 7-05 procedures with the seismic design parameters provided by the local expert committee and the geotechnical engineer. The parameters (Ss=1.545g and S1 =0.6g) were essentially the same as those at the center of San Francisco. This resulted in the maximum design spectrum acceleration (Sds) of 1.03g. Later, site specific ground acceleration studies were conducted at several construction sites in Baku that showed maximum design spectrum values approximately 25 percent less than the assumed values for SOCAR Tower. As shown in Figure 8, since the wind shear and overturning moments were greater than those of seismic loads (even though seismic load assumptions used for member checks were overestimated), they did not result in an overly conservative tower design.

Lateral Load Resisting System Design

The lateral resisting system of the tower is a dual system with Special Reinforced Concrete Shear Wall core and Special Steel Moment Frames. The core wall was detailed to accept significant in-elastic deformations under seismic events, working with perimeter steel special moment frames (Figure 9). The fundamental building periods were 4.71 seconds in east-west directions, 2.84 seconds in north-south directions, and 1.39 seconds in torsion. The tower lateral system was sized to satisfy wind performance in Baku's aggressive wind climate; the core wall thicknesses in the rectangular core plan was dictated by wind deflections in the short direction (east-west) mainly because moment frame stiffness for that direction is significantly reduced by the geometry of the structure. The lateral system design satisfies a tower wind deflection criterion of H/500 for overall deflection. In-elastic story drift due to seismic load is less than 0.020 limit per IBC code (IBC 2010).

The core wall thickness changes occur at two levels: 1,000 to 800 millimeters at level six and 800 to 600 millimeters at level 24; 600-millimeter-thick core walls continue up to the top of the building. Core wall reinforcement was dictated by the seismic detailing requirements. As required by the code, heavy confinement rebar was provided around the vertical reinforcement to prevent the sudden crushing of concrete during an earthquake.

Wind Load 风荷载	Seismic Loads 地震荷载
Basic Wind Speed, Vo = 53 m/s (50 years, 3 sec.) 基本风速，Vo ＝ 53m/s（50年，3秒）	Dual System with RC Core and Special Moment Frame, R=7 混凝土核心筒和特殊时刻框架双系统，R=7
Wind Exposure C 风向 C	Soil Site Classification D 土壤分类 D
	Seismic Design Category D 抗震设计类别 D
	Ss= 1.545g Sd=0.6g Ss= 1.545g Sd=0.6g
Importance Factor, I=1.0 重要性系数，I=1.0	Importance Factor, I=1.0 重要性系数，I=1.0
Vx = 1,830 T (service) Vx=1830 T（服务值）	Vux = 2,152 T (ultimate) Vux=2152 T（极限值）
Vy = 2,030 T (service) Vy=2030 T（服务值）	Vuy = 2,152 T (ultimate) Vuy=2152 T（极限值）
My = 146,640 T-M My=146640 T–M（服务值）	Muy = 160,015 T-M (ultimate) Muy=160015 T–M（极限值）
Mx = 196,400 T-M (service) Mx=196400 T–M（服务值）	Mux = 132,815 T-M (ultimate) Mux=132815 T–M（极限值）

Figure 8. Summary of lateral load parameters (Source: Thornton Tomasetti, Inc.)
图8. 侧向荷载参数小结（来源：Thornton Tomasetti, Inc.）

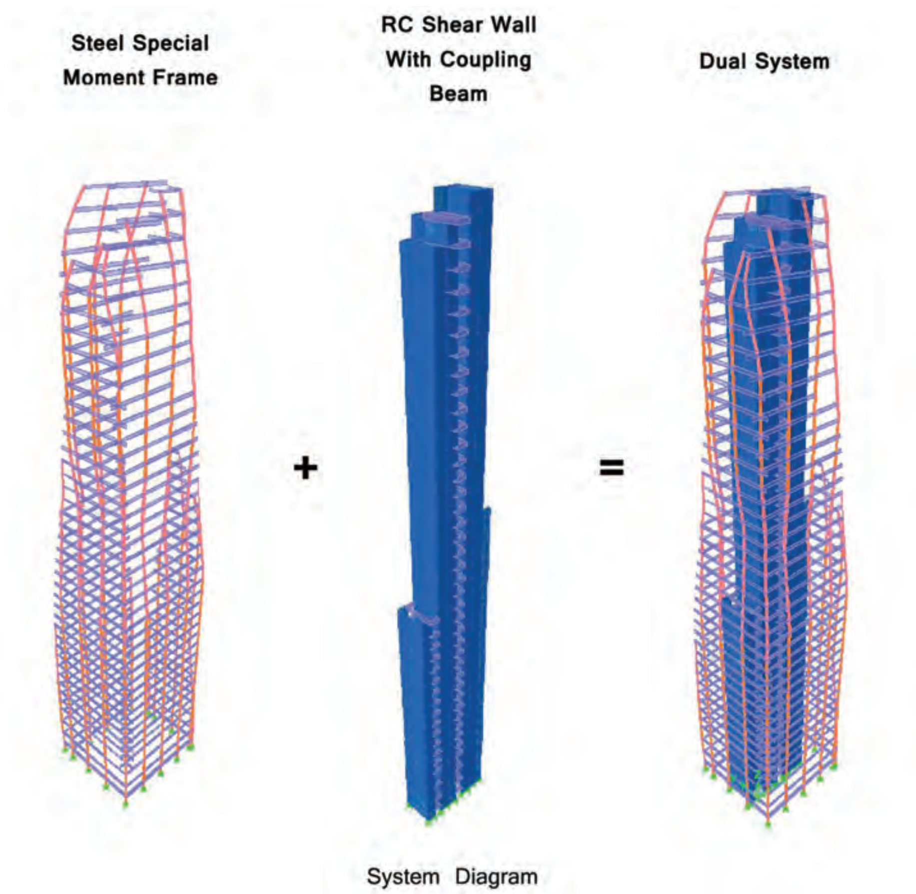

Figure 9. SOCAR Tower lateral resisting system (Source: Thornton Tomasetti, Inc.)
图9. 塔楼抗侧向力体系（来源：Thornton Tomasetti, Inc.）

外围特殊框架梁（SMF）构件一般为W920，使用RBS（削弱梁截面）“狗骨”构造。RBS截面在关键区域内在抗弯强度方面有约25%~30%的削弱。依据ASCE 7-10对双重体系的规定，应该创建一个单独的模型用以确认特殊受弯框架在重力荷载之外还能独立地承担总设计地震力的25%，尽管根据相对刚度，实际上它们一般并不会承担那么大一部分的地震力。

所使用的规范还要求进行强柱弱梁（SCWB）校核，以确保梁先于柱出现非线性行为。在梁柱节点处，柱子的总抗弯强度（Mpc）必须至少大于1.2倍的梁端抗弯强度之和（Mpb）。因为ETABS设计模块并不能考虑到削弱后的梁抗弯强度，而程序会假设对柱有更高的抗弯强度要求。作为替代，利用内部的计算表对RBS的属性进行了更适当和更反映真实情况的校核。

The core shear walls were fully integrated by link beams. Coupling beams linking core wall piers were designed as steel embedded reinforced concrete (SRC) members rather than diagonally reinforced link beams, due to dimensional constraints. With beam depths limited to 1,200-millimeter aspect ratios greater than three, the effectiveness of a diagonal reinforcement scheme would be reduced.

The perimeter Special Moment Frame (SMF) members are typically W920 with RBS (Reduced Beam Section) "dogbone" details. RBS sections have approximately 25 percent ~ 30 percent reductions in flexural strength at the critical zone. In accordance with ASCE 7-10 dual system provisions, a separate model was generated to confirm that the Special Moment Frames would be capable of resisting 25 percent of the design seismic forces independently in addition to gravity loads, even though by relative stiffness they would typically experience a smaller fraction of the seismic forces.

The code used also requires a Strong Column Weak Beam (SCWB) check to ensure the beam exhibits non-linear behavior before the columns. At each column-beam joint, the sum of the flexural strength of the columns (Mpc) framing in must be at least 1.2 times the sum of the flexural strength of the beams (Mpb) framing in. Because the ETABS design module is not able to calculate the reduced flexural strength of the beams, the program assumes higher flexural strength requirements for the columns; instead a more appropriate check reflecting RBS properties was done by an in-house spreadsheet.

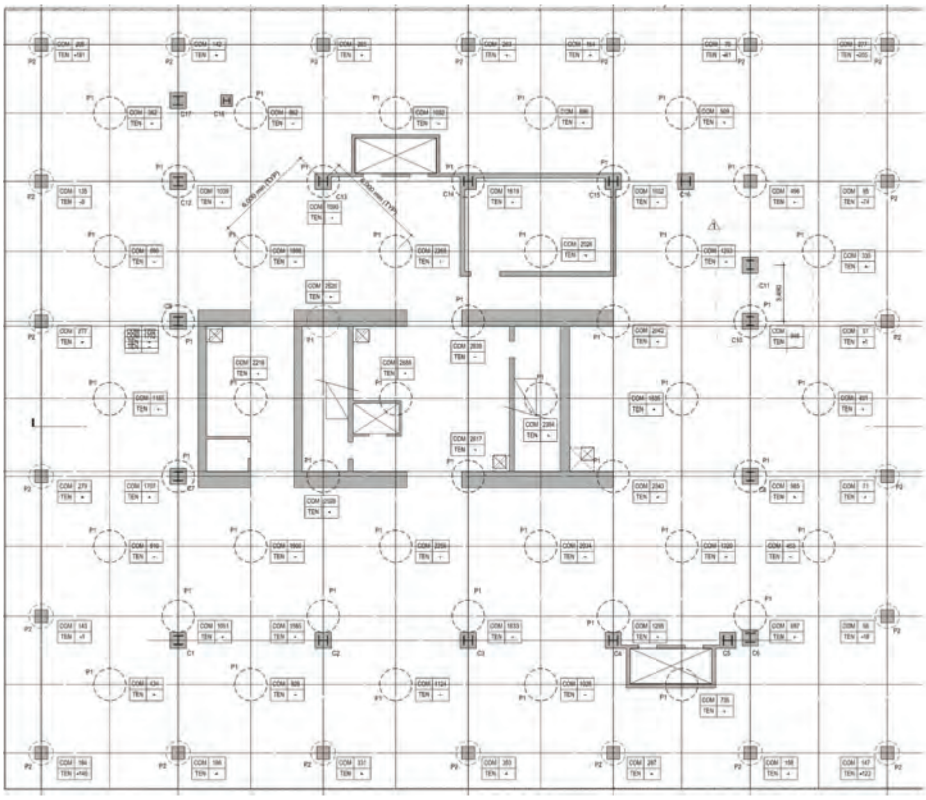

Figure 10. Foundation plan (Source: Heerim Architects & Planners)
图10. 基础结构平面图（来源：Heerim Architects & Planners）

Figure 11. Pile construction (Source: Tekfen Construction and Installation)
图11. 打桩作业照片（来源：Tekfen Construction and Installation）

Foundation Design

The tower foundation is a raft pile system – a 3.5-meter-thick mat on 48 two-meter-diameter Reversed Circulation Drilling (RCD) piles and 22 1.5-meter-diameter RCD piles which support the tower and transmit tower loads to sound rock below. The two-meter RCD pile has a compressive capacity of 2,400 tons and tensile capacity of 595 tons. The 1.5-meter RCD pile has a compressive capacity of 1,300 tons and tensile capacity of 335 tons (Figure 10).

A construction challenge was posed during the procurement of piling equipment for the pile installation under the tower. Due to the unavailability of piling machines with two-meter and 1.5-meter diameters, a complete redesign using a maximum diameter of 1.2 meters was proposed, based on the largest piling equipment available in Azerbaijan at that time. When it became clear while the piling construction was underway that such a redesign would cause a further significant delay on the foundation work, the construction team decided to purchase a new machine from overseas to make the two-meter diameter pile installation possible (Figure 11).

Tuned Mass Damper

Based on a wind tunnel study, the predicted peak accelerations of the building in the east-west direction was 28.5 milli-g for a one year return period for wind cases, 47.3 milli-g for five

基础设计

塔楼基础是筏板桩基系统。3.5米厚的筏板坐在48根2米直径和22根1.5米直径的反循环钻孔（RCD）桩上，桩和筏板支撑着塔楼并将塔楼荷载传递到桩端下方坚固的岩层里。直径2米的反循环钻孔桩具有分别为2400吨和595吨的抗压和抗拉承载力。直径1.5米的反循环钻孔桩具有分别1300吨和335吨的抗压和抗拉承载力（图10）。

在施工方采购打桩设备时遇到了一个难题。由于无法得到2米和1.5米直径的打桩机，如果按当时阿塞拜疆所能获得的打桩机最大直径——1.2m，需进行基础结构的

Figure 12. Tuned mass damper (Source: Heerim Architects & Planners)
图12. 调频质量阻尼器（来源：Heerim Architects & Planners）

Figure 13. Exterior LED lighting (Source: Heerim Architects & Planners)
图13. 外部LED灯光照片（来源：Heerim Architects & Planners）

years, and 58.8 milli-g for 10 years, assuming 1.5 percent of critical damping inherent in the structure. The predicted building accelerations in the north-south directions were substantially less than those in the east-west directions; however, the predicted building motions in both directions did not meet the suggested criteria for an office building per International Organization for Standardization (ISO) 10137 and 6897 (ISO 2007; ISO 1984). To improve tower serviceability, the wind tunnel consultant suggested installing a 600-ton supplementary Tuned Mass Damper (TMD) at the top of the building, located inside the flame shape (Figure 12). With the supplementary damper, building motion is predicted to satisfy the ISO criteria: 12 milli-g for one year and 17 milli-g for five years wind. The damper provides a comfortable environment for occupants, especially on the high floors, where executive offices and a sky lounge are located.

Façade Design

The office tower has a free-formed spiral shape to express the basic design concepts of fire, wind, and energy. Maximizing usable space and minimizing the gap between the building skin and the slab edge were top design priorities. After numerous façade design options were evaluated, considering various glass properties, panel shapes and sizes, and mullion profiles for strength, availability, constructability and cost, it was decided to use a rectangular typical curtain wall units throughout the tower while following smooth curvature exterior lines over most of the building except for corner conditions (Figure 13).

重新设计。当得知基础重新设计会使对基础施工进度造成极大地推迟延缓，施工队决定从海外新购一台可进行2米直径打桩作业的机器（图11）。

调频质量阻尼器

基于风洞研究，建筑东西向的预测峰值加速度为28.5 milli-g， 47.3 milli-g和58.8 milli-g，分别对应1年，5年和10年回归周期的风工况，假设结构固有临界阻尼为1.5%。建筑南北向的预测加速度大大小于东西向的预测值，然而，预测的在两个方向的建筑运动并没能达到ISO 10137和6897（ISO 2007;ISO 1984）关于办公建筑的建议标准。为提升塔楼舒适度，风洞顾问建议安装一个600吨的额外的调频质量阻尼器（TMD）在建筑顶端，放于火焰造型之内（图12）。有了阻尼器后，建筑运动满足了ISO的标准：12 milli-g和17 milli-g分别对应1年和5年风。阻尼器可提供一个舒适的居住使用环境，特别是对位于高层的经理办公室和空中休憩厅。

幕墙设计

办公大楼拥有自由地螺旋形状来表达基本设计理念：火，风，和能量。可使用空间最大化和建筑外皮和板缘间空隙最小化，是幕墙设计的首要考虑。经过对无数个外立面设计方案的评估，考虑了各式玻璃属性、镶板形状和尺寸，和出于强度、易得性、可建造性和造价考虑的竖框外形，最终决定在整座塔楼使用典型矩形幕墙单元，尽可能按照除角部以外的塔楼外轮廓曲面平滑布置（图13）。

抗爆优化设计

在建筑的施工阶段，决定实施更高等级的安全措施，反应了SOCAR大厦的战略重要性。这是在基础安检门和交通护栏之外的额外措施。由客户聘请的特别顾问进行了反爆炸设计研究，同时在最终的结构设计中，考虑了更多富余的结构荷载传力途径。作为对一些建议的回应，包括让结构在爆炸中适应力更强，同时在地下室2层提供避难区域，通过给主要结构构件增加额外的刚度和强度对结构设计进行升级。

新添的特殊避难区域位于地下室，被遮挡在费尽苦心连结在主体结构上的厚实钢筋混凝土翼缘墙之后。该避难区域可容纳约60人，并可在安全区域直接控制公司和建筑的运营。结构顾问对塔楼核心筒剪力墙和基础在极限情况下进行了重新分析，假设了翼缘墙的存在，优化了翼缘墙的布置和配置以最大化效能，并利用全三维施工顺序分析对翼缘墙进行了受弯以及受剪的设计。

总结和鸣谢

封顶后，SOCAR大厦成为了阿塞拜疆最高的建筑和国家地标。其设计灵感源自火焰、风和能量的图案，分别代表着阿塞拜疆、巴库和SOCAR。从反循环钻孔桩基础到塔楼结构和调频质量阻尼器的安装，SOCAR大厦引入了之前从未被在这个国家使用过的关于高层建筑的创造性设计和建造技术。SOCAR大厦按照IBC 2006规范（IBC 2006）设计。即使主体结构设计受风荷载的表现标准所控制，但它的抗侧力双重体系（特殊钢筋混凝土核心筒和特殊钢结构框架）依然被设计成能够抵抗在地震工况下产生的巨大塑性变形。根据风洞顾问的建议，位于屋顶的调频质量阻尼器（TMD）提升了塔楼风荷载下的使用性能。

在此，我们特感谢SOCAR给予我们的大量协助和指导。最真挚的感谢Heerim和Tekfen的设计团队和施工团队的成员们，感谢他们在整个项目期间不懈的努力、激情和耐心。

Blast Resistant Improvement Design

During the construction of the building, it was decided to implement higher security measures reflecting the strategic importance of the SOCAR Tower. This was in addition to the basic security gates and traffic barriers. Anti-blast design was studied by the special consultant retained by the client and redundant structural load paths were considered in the final structural design. In response to recommendations to make the structure more resilient under blast loading, and to provide a refuge area in the second basement floor, structural upgrades provide additional stiffness and strength capacities to primary structural elements.

The newly added special refuge area – located in the basement and shielded by thick reinforced concrete fin walls painstakingly tied to the already installed building structure – is able to house about 60 people who can command the operation of the company and the building from the secured area. The structural consultant re-analyzed the tower core wall and foundation under ultimate conditions assuming the presence of the prescribed fin walls, optimized the fin wall layout and configuration for maximum efficiency, and designed the fin walls for all flexural and shear loads imposed using a full 3-D construction sequence analysis.

Conclusion and Acknowledgements

Upon topping out, SOCAR Tower became the tallest tower in Azerbaijan and a national landmark. Its design was inspired by the motifs of fire, wind, and energy, which represent Azerbaijan, Baku, and SOCAR, respectively. From the RCD pile foundation to the tower structure and the TMD installation, SOCAR Tower has introduced new innovative design and construction technologies related to high-rise buildings not previously used by the construction practice in this country. SOCAR Tower was designed in accordance with the IBC 2006 code (IBC 2006). Its lateral dual system of Special Reinforced Concrete and Special Steel Moment Frames are detailed to resist significant in-elastic deformations under seismic events, even though design proportions are controlled by the wind performance criteria. A roof-level TMD improves the tower wind serviceability based on the wind tunnel consultant's recommendation.

We would like to thank SOCAR for their abundant helpful assistance and guidance. Deepest gratitude is also due to the members of the design team and construction teams at Heerim and Tekfen for their efforts, hard work, passion, and patience through to the completion of the project.

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