Title: **Advances in Seismic Design and Construction in Indonesia**

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Subject: Seismic

Keywords: Performance Based Design
Seismic

Publication Date: 2014

Original Publication: CTBUH 2014 Shanghai Conference Proceedings

Paper Type:
1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Advances in Seismic Design and Construction in Indonesia

印度尼西亚抗震设计和施工的发展

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Davy Sukamta is the principal of Davy Sukamta & Partners – Structural Engineers. He is the immediate past president of Indonesian Society of Civil and Structural Engineers, where he served the association for four consecutive terms during 1999-2011. His field of specialism is in seismic design of buildings including the use of base isolation system and the design of deep basements. He has designed many tall buildings in Jakarta including the Pakubuwono Signature, a 250 Meter-high residential tower which is currently the tallest completed building in Jakarta.

Davy Sukamta是Davy Sukamta结构工程事务所的负责人。他是印尼市政和结构工程学会的前任会长，从1999至2011年间连任了四个学期。他在建筑抗震设计中专攻领域包括地基隔离系统以及深地基设计。他在雅加达设计了多个高层建筑，包括目前雅加达建成建筑中最高的250m公寓楼Pakubuwono Signature。

Abstract

Since the Great Aceh Earthquake of 2004, much progress has been achieved in Indonesia with the aim of building better earthquake resistant structures. The seismic map has been revised which has taken the recent events into account, the seismic code has been renewed, and interest in the society to provide better-performing structures during seismic event has been awakened. These result in more rigorous analysis procedures being adopted and the use of base isolation system for high-rise buildings.

This paper highlights the advances in seismic resistant design and construction practice in Indonesia, from the development of the new code to the state of practice in design office and the application of new technology in the construction industry.

Keywords: Earthquake Resistant Design, Performance-Based Seismic Design, Response Spectrum Analysis, Nonlinear Response History Analysis, Base Isolation System

摘要

自2004的亚齐 (Aceh) 大地震之后，印度尼西亚在提升建筑结构抗震性能上有了大量的进展。根据最近发生的种种事件震区地图被重新修正，抗震规范也进行了更新，社会中对于增强建筑抗震性能的意识也被唤醒。这导致了在高层建筑的地基隔离系统中应用了更加严格的分析程序。

本文展示了在印度尼西亚抗震设计的进展以及工程实践，从新规范的制定到设计事务所设计实践中的运用再到施工工业中新技术的引入。

关键词: 抗震设计，基于性能的抗震设计，回应范围分析，非线性回应历史分析，地基隔离系统

Introduction

Indonesia is located in a highly active seismic region, at the point of convergence of three major tectonic plates and nine smaller plates. After the Northern Sumatra - Andaman (Great Aceh) Earthquake of December 2004 and then followed by a series of several major earthquakes in the Sumatra and Java which brought serious damages to the major city of Yogyakarta and Padang, the community started to consider the earthquake risk more seriously. The engineering practice in designing seismic resistant structures in Indonesia has evolved from the equivalent lateral static procedures to nonlinear response history analysis in the span of forty years. These advances are the result of the availability of PCs and computer programs as design aids and the dissemination of latest knowledge and research in seismic resistant design by international and national institutions. Although the everyday office practices still use Linear Response Spectrum Analysis for seismic design, the Performance-Based Seismic Design (PBSD) following the guidelines from the PEER Tall Buildings Initiative has been applied in the design

简介

印度尼西亚处在一个地震活动高度活跃的区域，正好位于三个主要构造板块和9个小的构造板块撞击点处。在2004年12月在苏门答腊和爪哇岛发生的北苏门答腊-安达曼 (Great Aceh，大亚齐) 大地震以及之后一系列的余震给如日惹 (Yogyakarta) 和巴东 (Padang) 的大城市带来了巨大的破坏，人们开始重新严肃地看待地震风险。印度尼西亚在抗震结构设计上的工程实践起源于同期持续40年的对于非线性回应历史分析的侧向静态程序。这些进步得益于设计中电脑辅助手段的运用以及国际上和国家内各个机构对于抗震设计的最新知识和研究的传播。尽管大部分的公司在抗震设计中依旧使用线性回应范围分析，近年来几个高层建筑开始使用根据PEER高层建筑提案的基于性能性抗震设计 (PBSD) 方法。由于高层建筑的建设，印尼的地震风险率翻了一番，因此我们相信在不远的未来这一手法会越来越受欢迎。

印尼的新地震规范在2012年颁布。新的规范运用了地震工程学上最新的知识，根据新一代的衰减图谱和3D地震源分布来绘制了印尼新的地震图。最新的地震断层变化和发现都被考虑进去，导致了在印尼很多

of special tall buildings recently. With the growth of tall buildings in Indonesia coupled with the high seismicity risk, it is believed that this practice will gain popularity in the near future.

The new seismic code of Indonesia has been issued in late 2012. The code uses the latest knowledge in earthquake engineering, among others the use of New Generation Attenuation and 3-D seismic source to develop the seismic map of Indonesia. Recent major events and findings on new earthquake faults have been considered, resulting in map with higher spectral acceleration in many areas of Indonesia. The provisions of this code refer closely to ASCE 7-10 and IBC 2009.

On the construction aspect, other than innovative structural system like core wall with outriggers, the use of base isolation system has gained momentum in Indonesia. To mitigate the risk of seismic effects on building, its contents and occupants, the response of the structure is modified using this system. Three prominent high-rise office buildings in Jakarta, one of which has been completed in 2012, have been designed as seismically isolated structure using high damping rubber bearings. Several other low-rise buildings have also been built or under construction as seismically isolated structures in Jakarta and Padang.

Development of the New Indonesian Seismic Code

Indonesia has a very high seismic activity due to its location with several major active tectonic plates colliding in the region. Several major earthquakes stroke Indonesia in the past decades, most notably are the Sumatra-Andaman M9.1 earthquake in December 2004 with 227,898 fatalities, the Java M6.3 earthquake in May 2006 with 5,749 fatalities and the Southern Sumatra M7.5 earthquake in September 2009 with 1,117 fatalities. The latest two hit big cities of Yogyakarta and Padang and have caused damages to both engineered and non-engineered structures. The damage of engineered structures opened the eyes of the government on the need of a better practice in seismic resistant design in the country, from code updating and seismic map revision to design procedures and construction practice for buildings. Several earthquakes shaking in Jakarta in past decade have also awakened the community to the need of seismic resistant building and have eventually led to the use of base isolation structures.

There were many cases of collapse of engineered structures in Yogyakarta and Padang during the 2006 and 2009 earthquakes, which should not be expected from a seismic resistant building. In Padang, one academy building has a total collapse causing many fatalities (see Figure 1). In most cases the detailing of reinforced concrete components do not comply with code requirements. Many basic mistakes were found in the observed structures, most notably the lack of stirrups in beams, no stirrups in beam column joint (see Figure 2) and lack of confining steel in columns.

Advances in seismic design and construction in Indonesia are progressing in three different aspects: the issuance of revised seismic map and 2012 code, the use of more rigorous analysis in the design of special structures and the application of base isolation system for low-rise and high-rise buildings. Indonesian seismic code has been revised a few times and each time corresponding with revised seismic maps. The first modern code was issued in 1983, and then revised in 2002 and recently in 2012. The 1983 code adopts many of the New Zealand standards of practice, and introducing the use of capacity design principles for seismic resistant design of buildings. Strong column - weak beam concept was applied. Brittle failure must be avoided. The

地区呈现出更高的谱应加速度。规范大量地参考了ASCE7-10以及IBC2009。

在施工方面，很多创新的结构体系例如核心筒加悬臂框架、地基隔离系统都在印尼有了相应的实践。为了减缓地震危害对于建筑、内部物体以及使用者的影响，使用了这些系统来调整建筑的回应幅度。雅加达的3栋知名高层建筑，其中2012年完工的一栋就使用了高阻尼橡胶底座来实现地震隔离结构。雅加达和巴东的其他数个在建或建成的多层建筑都使用了这种地震隔离结构。

发展具有印度尼西亚特色的新地震规范

印度尼西亚处在几个主要活动版块的碰撞地带，是一个地震活动高度活跃的区域。在过去的数十年间遭遇了几次严重的地震灾害: 最有名的2004年十二月发生的苏门答腊-安达曼9.1级地震，造成了227，898人伤亡; 2006年五月的爪哇6.3级地震，造成5.749人伤亡; 2009年南苏门答腊的7.5级地震，造成1，117人伤亡。后两者侵袭了日惹和巴东，给工程结构和非工程结构都带来了损害。工程结构遭受的巨大损害让政府意识到这个国家对于提升抗震设计的需求，对于规范的改进到震度图修正再到建筑设计阶段和施工实践各个环节提升的需求。过去几十年里雅加达的几次地震也唤起了人民对于抗震建筑的渴望，并最终导致了地基隔离结构的运用。

Figure 1. Total collapse of building in Padang during the S.Sumatra M7.5 EQ in 2009 (Source: Davy Sukamta)
图1. 2009年南苏门答腊7.5级地震中巴东一栋完全坍塌的建筑 (来源: Davy Sukamta)

Figure 2. Beam-column joint failure in RC Beam in Padang during the S.Sumatra M7.5 EQ in 2009 (Source: Davy Sukamta)
图2. 2009年南苏门答腊7.5级地震中巴东的梁柱体系连接的破坏 (来源: Davy Sukamta)

2002 code refers to US standards of practice with adoption of many of the UBC 1997 provisions, while the 2012 code adopts many of the ASCE7-10.

While the 2002 code divides the region of Indonesia into several seismic zones and assigned each for a given peak ground acceleration at bedrock for 10% probability of exceedance in 50 years, the new 2012 uses spectral response acceleration contour maps for target risk of structural collapse equal to 1% in 50 years. The maps were developed using the latest technique available including use of 3-D earthquake sources, use of New Generation Attenuation and inclusion of fragility factor, with 5% damping. It takes the effect of local soil condition into considerations. Newly found seismic sources have been included and estimated maximum magnitude of seismic sources has been revisited based on recent events. While the 2002 seismic map indicates Jakarta has 0.15g PGA for 475-year earthquake, the 2012 map shows a higher value of 0.25-0.30g for 2475-year earthquake (see Figure 3). Following US practice, map for short period is also developed (see Figure 4) as well as for 1 second period (see Figure 5).

The 2012 code contains many provisions not stipulated in earlier code; among others are the redundancy factor and the need to check for irregularities of the structure, seismic design category and related height limitation for a given structural system. For Jakarta, the mapped acceleration parameters are such that most if not all buildings will fall into seismic design category D. Consequently the type of structural system is restricted if the building is higher than 75 meter. If the engineer wants to use novel structural system, he must resort to other more rigorous method such as PBSD. Although still in its beginning, structural engineers in Indonesia have started to use performance-based seismic design in limited cases, especially for taller buildings with non-descriptive structural system.

State-of-Practice in Design Office in Indonesia

Indonesia is currently experiencing construction boom. Many high-rise buildings are being designed and built especially in the municipality of Jakarta. Currently it is common to have 40 to 50-story building with subterranean structures between 3 to 6 stories deep. Some buildings taller than 50-story are being designed as well, among others the Signature Tower, the Pertamina Tower and the China Sonangol Tower. Modern lateral-force resisting system such as core wall and outrigger has been used in several buildings in the past, with the 52-story Amartapura residential tower being the first applying it in 1995. Current design practice uses core wall and outrigger with belt truss and mega frames for supertall or megatall building. To reduce the weight of the building, composite structure or mix steel concrete is used as well.

Permit submission in Jakarta must be performed by a licensed professional engineer, reporting all the design assumption, modeling and analysis, and design of structural components. The report is subject to review by expert panel team. Modal response spectrum analysis is often used for design of common buildings. For structures outside the considered normal category, the team often asks the designer to perform more rigorous analysis. In many cases a push-over analysis must be conducted. For super or megatall buildings performance-based seismic design is required. The procedure for PBSD follows the PEER TBI and SNI 1726:2012 / ASCE 7-10 documents. The latter is used for selection and modification of ground motions to develop the time series and the number of pair of ground motions to be used in the analysis. The first building in Indonesia designed

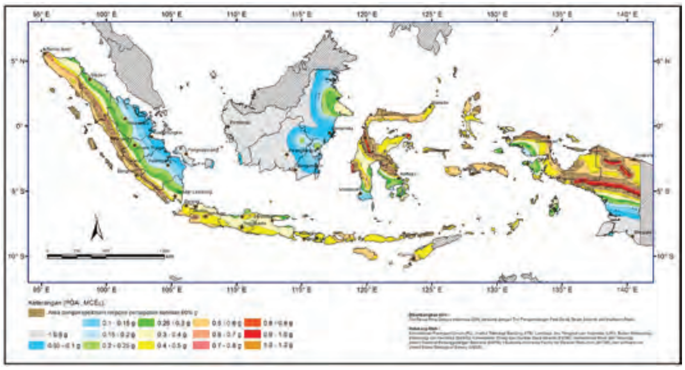

Figure 3. PGA, Risk-Adjusted Maximum Considered Earthquake (MCEr) Ground Motion Parameter, Site Class SB (Source : SNI 1726:2012)
图3. 地面峰值加速度，风险调整最大地震强度值 (MCEr) 下的地面运动参数，基地分级为SB (来源: SNI 1726:2012)

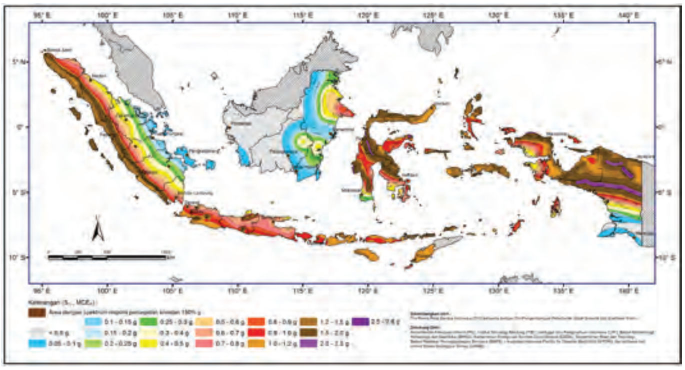

Figure 4. Ss, Risk-Adjusted Maximum Considered Earthquake (MCEr) Ground Motion Parameter, Site Class SB (Source : SNI 1726:2012)
图4. Ss，风险调整最大地震强度值 (MCEr) 下的地面运动参数，基地分级为SB (来源: SNI 1726:2012)

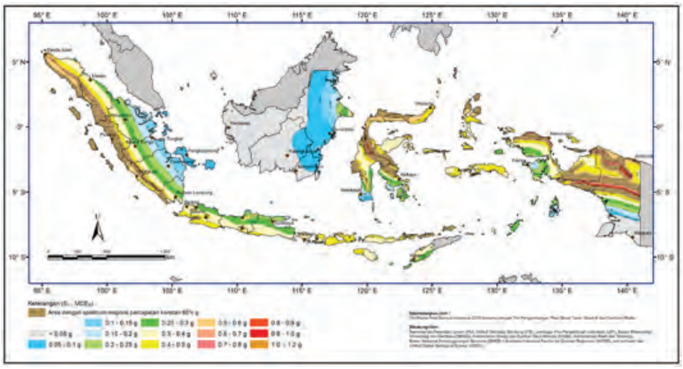

Figure 5. S1, Risk-Adjusted Maximum Considered Earthquake (MCEr) Ground Motion Parameter, Site Class SB (Source : SNI 1726:2012)
图5. S1，风险调整最大地震强度值 (MCEr) 下的地面运动参数，基地分级为SB (来源: SNI 1726:2012)

日惹和巴东从2006年到2009年地震期间处处能看见坍塌的建筑，这绝不是一个具有抗震力的建筑该出现的。在巴东，一个学校建筑完全坍塌导致了很多伤亡 (见图1) 。很多时候，钢筋混凝土建筑的构件配筋并没有遵守建筑规范要求。在对于一些建筑的检查中法向了很多基本的错误，最常见的比如柱子上没有箍筋，梁柱结合出没有箍筋 (见图2) 以及柱子中没有配筋。

印尼在抗震设计和建造上进展体现在以下三个方面: 修正震区图和2012年规范; 特殊结构设计中个更加严格的分析; 多层和高层中地基隔离系统的运用。印尼地震规范随地震分区图修改过几次。现代的第一版规范与1983年颁布，在2002和2012年分别修改过。1983年版的规范大量参考了新西兰的实践规范，在建筑抗震设计中引入了容量设计原则。使用了强柱-弱梁的策略。避免易脆结构。2002年的规范参考了美国实践规范，也采用了UBC1997年的条例，而2012年的则引入了很多ASCE7-10规范。

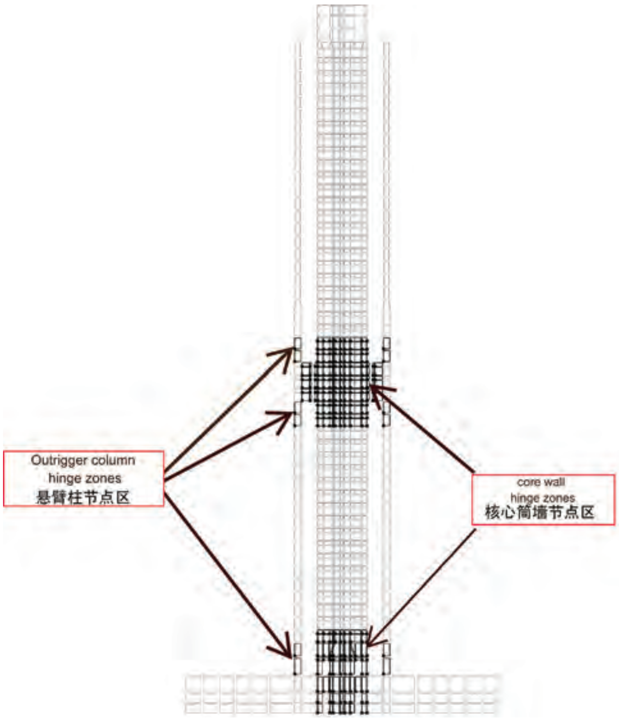

Figure 6. The 250-meter high 50-story Pakubuwono Signature residential tower, the first one designed with performance-based seismic design procedure in Indonesia (Source: Davy Sukamta)
图6. 250m高50层的Pakubuwono Signature 住宅楼，印尼第一栋设计了性能化抗震设计程序的建筑物 (来源: Davy Sukamta)

following PBSD procedure is the 250 Meter-high Pakubuwono Signature, a 50-story residential apartment with single system RC core wall and outriggers for lateral-force resisting system, completed in 2014. The structure is modeled with fiber elements for the core wall and columns where yielding is expected (see Figure 6). The building is designed by Davy Sukamta & Partners structural engineering firm in Jakarta in 2011.

Advances in the Use of Seismic Protection System in Indonesia

After the Northern Sumatra - Andaman (Great Aceh) Earthquake of December 2004, many parties started to realize the importance of having better earthquake resistant structures. Some big private sectors have demanded to have a higher level of seismic performance objective for their corporate building. This gave birth to the use of seismic isolation system for high-rise buildings in Indonesia. The first seismically isolated high-rise building in Indonesia was completed in 2012 for a cigarette company who had specifically included in their design brief the use of base isolation system for their new corporate head-office in Jakarta. The use of base isolation system has been well proven in Japan and USA in many earthquake events, most notably in the case of USC hospital in Los Angeles and in the performance of base isolated buildings in Sendai area during the 2011 M9.0 Tohoku earthquake.

The Gudang Garam Head Office building is a 26-story, 116.2-meter high seismically isolated structure in Jakarta, consisting of 3-level subterranean structure plus two levels of podium and 21-story office tower on top of it. The isolation interface is at Basement-3 floor (see Figure 7). The building is designed by Davy Sukamta & Partners structural engineering firm in Jakarta. High damping rubber bearings produced by Bridgestone Japan are used to separate the foundation from the super-structure. Forty of these were installed, ranging from 1.3-meter to 1.5-meter in diameter using off-the-shelf isolator designs

2002年的规范将印度尼西亚划分成了数个地震区，以超出50年一遇的地震强度10%的数值来评估各个区域的地面加速度峰值，2012年 的新规范使用了谱应加速度地形图，在50年一遇的地震中能将结构坍塌风险降低到1%。这张地图使用了包括3D震源分析，新一代衰减，阻尼为5%的易脆因素等最新的技术，最近检测出的震源被添加进去，估算最大震源强度也根据近期的事件重新设定。2002年的震区图中雅加达在475年一遇的地震中地面加速度峰值可达到0.15g，2012年震区图中在2475年一遇的地震中会达到0.25-0.3g (见图3) 。根据美国的经验，还绘制了短期内的分区图 (如图4) 和每秒的情况图 (图5) 。

2012年规范包含了之前规范中没有提及的多个条款; 比如多余因素、对结构不规律性的核查、抗震设计分级和相应对于特定结构体系的高度限制。在雅加达这样的加速度峰值下，不说全部，大部分建筑都会被划入抗震设计中的D类。结果就是建筑超过75m的话，他的结构形式就会受到限制。如果结构师想要使用新型的结构体系，那他就必须依赖于其他更为严苛的抗震设计手法比如PBSD (基于性能的抗震设计) 。尽管刚刚起步，印尼的工程师们已经开始在一些案例中使用了性能化抗震设计，特别是在那些结构体系难以定义的高层建筑中。

印度尼西亚设计事务所的实践进度

印度尼西亚现在正处在一个建设大潮中，许许多多的高层建筑在被设计和建造，其中以首都雅加达为甚。现今40-50层的建筑常常会包含3-6层地下层。也有一些超过50层的建筑，比如Signature Tower，Pertamina Tower，China Sonangol Tower。现代的侧向荷载体系例如核心筒加悬臂框架在几个完成的建筑中都有使用，第一次是在1995年52层的Amartapura公寓楼中。目前的高层和超高层设计实践中会使用核心筒、悬臂、环绕桁架和巨型框架。为了减轻建筑自重会使用复合结构或是钢混结构。

雅加达建筑的许可证申请必须由注册工程师提交，报告需要包含所有的设计估算，模型和分析，结构构成的设计。这份报告会有专家评审小组来审核。一般的建筑需要进行形态回应程序分析。而对于非常规的结构类型，小组会要求设计师提供更为严格的分析。很多情况下需要进行超出峰值的分析。对于高层和超高层建筑就要求有性能化抗震设计。PBSD (性能化抗震设计) 以PEER TBI和SNI 1726: 2012/ASCE 7-10 为规范依据。后者用于确定地面振动的选择和调整，从而确定时间序列以及分析中地面振动的次数。印尼第一栋使用了PBSD的高层建筑是250m高的Pakubuwono Signature，这栋2014年完工的50层住宅公寓楼使用了钢筋混凝土核心筒和侧向悬臂荷载结构体系。结构在可能产生形变的地方的核心筒和柱子中加入了纤维成分 (如图6) 。这个建筑由Davy Sukamta & Partners结构工程事务所2011年在雅加达设计。

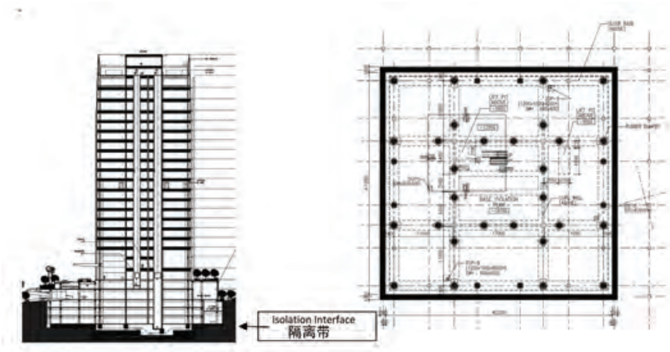

Figure 7. Cross section and plan of isolators of the Gudang Garam Office Tower (Source: Davy Sukamta)
图7. Gudang Garam办公楼的剖面和阻尼器分布平面 (来源: Davy Sukamta)

Figure 8. High damping rubber bearings in Gudang garam Office Tower (Source: Davy Sukamta)
图8. Gudang Garam办公楼的剖高Zuni橡胶轴承 (来源: Davy Sukamta)

(see Figure 8). The isolators were manufactured and tested in Japan and shipped to Jakarta. Mix steel concrete construction has been used in this building to reduce the weight, seismic mass and corresponding overturning moment. Lateral force-resisting system is RC core wall and outrigger, which has a natural period of 4.23 second as seismically isolated structure and 1.66 second as fixed-based. The gravity resisting system consists of composite RC slab on metal deck and steel trusses supported by perimeter steel columns and RC core wall.

The 2.5 seconds shift in the period between fixed base and isolated structure reduces the seismic-force and story drift responses of the building, enabling a much higher seismic performance level compared to a conventional system. The outrigger reduces the overturning moment in core wall and stiffens the structure to obtain the desired behavior. Table 1 shows the dynamic characteristics of the seismically isolated structure, where the first modes have almost 100% of modal participating mass (see Table 1). Site specific response spectrum analysis has been conducted and the building is designed for 0.28g PGA. Design procedure for the building follows ASCE 7-05 since it was designed when the revised Indonesian seismic code has not been issued. RSA is used for preliminary design and NLRHA for final design, using a suite of three pairs of appropriate ground motions. A total of 18 runs were performed to take variation of stiffness of isolator into account and the maximum value of the response parameter of interest is used for design.

The structure is modeled using linear elastic representations for all structural frame elements. The isolation system is modeled using non-linear characteristics for the elastomeric isolators used, i.e. a bilinear biaxial (shear) hysteretic element with linear axial stiffness. The properties of the isolator elements used in the analysis of the structure has considered maximum allowable variations of system stiffness and damping properties, by using a variation of 15% in the stiffness value. For force response calculations, an upper bound stiffness value is used; for displacement response calculations, a lower bound of specified range values is used. The performance of base isolated structure compared to the fixed one is demonstrated in the story drifts of the two systems (see Figure 9). The increased performance is clearly demonstrated here. Under MCE condition the seismically isolated structure remains in fully operational condition.

Maximum displacement response obtained from the DBE time history runs is used to establish the Design Displacement and Total Design Displacement values for the isolation system. The displacement values

Area 区域	Mode No. 编号	Period 周期	Modal Participating Mass Ratios (% Mass) 形态体量比例 (%体量)		
		(Second) (秒)	Ux-Trans X轴形变	Uy-Trans Y轴形变	Rt-Trans Rt形变
Tower 塔楼	1	4.23	0	99.05	0
	2	4.16	99.2	0	0.18
	3	3.45	0.18	0	99.63

Table 1. Dynamic characteristic of Gudang Garam Tower as seismically isolated system (Source: Davy Sukamta)
表1. Gudang Garam办公楼使用了地震隔离系统后的动力学特征 (来源: Davy Sukamta)

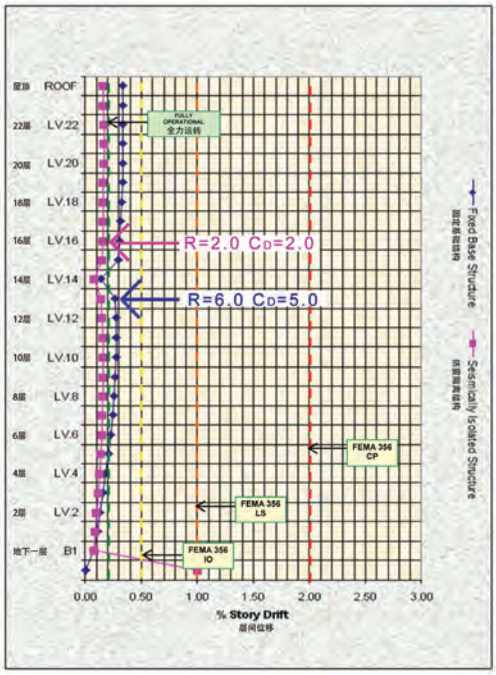

Figure 9. Comparison of story drift of seismically isolated vs. fixed base structure for MCE condition in Gudang Garam Office Tower (Source: Davy Sukamta)
图9. 在最大可能地震条件下，Gudang Garam办公楼地基隔离结构与固定结构在层间剪力上的差别 (来源: Davy Sukamta)

印度尼西亚抗震防护系统的应用发展

在2004年十二月的北苏门答腊-安达曼 (亚齐) 地震发生后，相关单位开始意识到更好的抗震结构的重要性。很多大型私人部门开始要求他们的办公楼有更高的抗震等级。这触发了地震隔离系统在印尼高层建筑中使用。印尼第一栋使用了地震隔离系统的建筑是2012年完工的某烟草公司办公楼，该公司在对于雅加达新的企业总部设计要求中就特别指明需要使用地基隔离系统。日本和美国的多次地震都证明了地基隔离系统的优点，尤其是洛杉矶的USC医院这一例子，以及仙台市的地基隔离建筑在2011年东北地区9.0级地震中的优越表现。

Gudang Garam总部办公室是位于雅加达的一栋26层，116.2m高的抗震隔离建筑，包括地下3层、2层裙房和上方21层的塔楼 (见图7) 。这个建筑由Davy Sukamta & Partners在雅加达的结构工程事务所设计。使用了日本普利司通公司生产的高阻尼橡胶轴承将地基和上部大型结构隔离。一共使用了40个标准化生产的阻尼器，直径从1.3m-1，5m不等。这些阻尼器在日本制造以及检测，之后被运来雅加达。建筑使用了混合钢筋混凝土结构来减少自重、激振质量以及相应的倾覆临界点。侧向荷载系统依靠的是钢筋混凝土核心筒和悬臂，以抗震隔离结构来做的话自振周期为4.23秒，而固定地基的话自振周期为1.66秒。重力荷载系统则由金属板上的复合混凝土板以及由周边一圈钢柱和钢筋混凝土剪力墙支撑的钢铁桁架构成。

mentioned are the vectored sum of orthogonal displacements, taken at every time step during the time history. Maximum displacement response obtained from the MCE time history runs is used to establish the design values for Maximum Displacement and Total Maximum Displacement values for the isolation system. Separation of the isolated structure from the basement structure is 600mm, slightly greater than 530mm calculated for maximum displacement. The use of core wall and outrigger system is very effective in reducing the overturning moment in the core wall, and stiffens the structure. Reduced overturning moment helps in limiting the tensile force in the isolators under the core wall. Some tensile force still occurs but the values are below the allowable ones.

Bored pile diameter 1.2 meter is used for the foundation system. Effective length of the pile is 32 meter and it has allowable vertical load of 415 metric tons. For gravity resisting system, steel frames with composite metal deck – RC slab is used. Composite steel truss spans 11.2-meter from the RC core wall to the perimeter column. For steel moment frame, prequalified moment connections are used. The simple form of the building can be clearly seen while under construction and after completion (see Figure 10).

Currently several other high-rise buildings in Jakarta are being designed and constructed as seismically isolated system: the Puri Matahari tower and the head-office building of a big Indonesian company. All of them are for office use. The Puri Matahari tower is a 27-story seismically isolated building under construction equipped with 38 numbers of high damping rubber bearings, consisting of 7 nos.HT90, 9 nos.HT120, 10nos.HT130 and 12nos.HT160. The building is expected to be completed in 2015. Another big office tower is under design, a 28-story seismically isolated system with 58 nos. of HDRB, 1.0M to 1.4M in diameter and large floor plate of 3,000sq.m per floor. Besides the three high-rise buildings illustrated above, some low-rise buildings in Padang and one embassy building in Jakarta have also been constructed with this system.

Although the adoption of base isolation system looks promising for the start, in the author's opinion it will take some time for this system to gain popularity. If the superior performance of the system has been demonstrated by real earthquake shaking, a new era in the use of base isolation system can then emerge in Indonesia.

Figure 10. Gudang Garam Office Tower during construction and after completion (Source: Davy Sukamta)
图10. Gudang Garam办公楼施工中和建成后 (来源: Davy Sukamta)

固定地基和隔离地基在结构自振周期上2.5秒的差异能够减小建筑的地震受力以及层间剪力。比起传统体系能够拥有更好的抗震性能。悬臂减小了核心筒倾覆可能性，对结构进行了加固以获得更好的表现。表1展示了地震隔离结构的动力学特征，第一种模式中基本包含了100%的形态体量 (如表1) 。经过对基地的回应谱研究将建筑基地地面加速度峰值设为0.28g。因为印尼抗震规范修订版还没有颁布，这个建筑的设计过程遵循的是ASCE7-05规范。初步设计使用了RSA，最终设计使用管理NLRHA，地面设定了3对振动。针对不同强度的阻尼器以及回应参数的最大值，总共进行了18轮模拟。

建筑所有的结构框架构件都使用了线性弹性代理。隔离系统中的弹性隔离器，换言之也就是具有轴向强度的双线性双轴 (剪力) 滞后性构件，则是非线性的。隔离器在结构分析中属性设定考虑了结构强度和阻尼特性的最大差量，例如强度值就会有15%的差量。在受力回应估算中，会使用强度最大值; 在形变回应估算中则会使用值域中的最小值。地基隔离结构的性能与固定结构性能上的差别在层间剪力上就能体现出来 (见图9) 。我们能明显看出性能的改善。在MCE (最大可能地震) 条件下地震隔离系统也能完全维持运行。

在DBE时段内的出的最大变形回应会被用来决定隔离系统的设计变形和总设计变形值。这个变形值指的是时间段内每一时间点得到的垂直变形的矢量和。在MCE时段内的出的最大变形回应会被用来决定隔离系统的最大设计变形和总设计最大变形值。隔离结构和地基结构之间有600mm的间隔，比起最大变形条件下估算出的530mm要略大。核心筒以及悬臂体系的使用能有效地减小核心筒倾覆临界点，并增强结构强度。减小倾覆临界点能够帮助减小核心筒下面隔离器所受到的拉力。仍旧会有部分拉力存在，但远远小于允许值。

地基系统使用了直径1.2m的螺旋钻孔桩。桩基的有效深度是32m，能够承受415吨的垂直荷载。重力荷载受力系统使用的是钢框架和符合金属板-钢混板。复合钢铁桁架从核心筒挑出11.2m搭在外圈的柱子上。钢框架结构中运用了预力矩连接。建筑简洁的形式在施工时和建成后都能清晰可见 (见图10)

现在雅加达的多栋高层建筑都设计和建造了抗震隔离系统: Puri Matahari塔还有一个印尼大型公司的总部办公楼。他们都是办公建筑。Puri Matahari是一栋在建的27层拥有38个高阻尼橡胶轴承的地震隔离建筑，其中包括了7个HT90阻尼器，9个HT120，10个HT130，12个HT160。建筑预计于2015年完工。另外这栋处在设计阶段的使用了地震隔离系统的高层办公楼，有28层单层面积达到3000平方米，使用了58个1.0m-1.4m直径不等的阻尼器。除去上文所讲的3栋高层建筑，巴东的一些多层建筑还有雅加达的一个使馆建筑也使用了这个系统。

尽管这个地基隔离系统的使用有一个充满希望的开端，笔者认为它的推广依旧需要一些时间。如果这个系统优越的性能能够在真实的地震情况下得到验证，那才是印度尼西亚地基隔离系统使用新纪元的开始。

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