Title: **Preventing Mega Disasters in Megacities - Code & Construction Challenges in the Indian Subcontinent**

Authors: Steven Baldridge, President, Baldridge & Associates Structural Engineering, Inc. (BASE)
Anantha Chittur, Senior Associate, Baldridge & Associates Structural Engineering, Inc. (BASE)

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Preventing Mega Disasters in Megacities - Code & Construction Challenges in the Indian Subcontinent
防止巨型城市的巨大灾害——印度次大陆的规范和施工的挑战

Steven Baldridge
President | 主席
Baldridge & Associates Structural Engineering, Inc. (BASE)
BASE结构工程公司
Chicago, USA | 芝加哥，美国

Steven Baldridge has over 30 years of experience as a structural engineer and has worked on more than 75 major projects internationally. Some notable projects include 37 high-rises located in areas of high seismic activity, such as India, Guam, and Hawaii. Additionally, Baldridge is actively involved with civic and professional organizations, embracing the latest technologies while showing interest, concern, and leadership for all aspects of the design and construction industry, including volunteering to respond to earthquake disasters in Guam, Hawaii, Samoa, Haiti, and Nepal.

鲍德里奇先生作为一名结构工程师，拥有超过30年的工作经验，参与了美国及国际上超过75个大型项目。他参与的项目包括37栋位于印度、关岛和夏威夷这样的高地震区的高层建筑。他积极参与民间和专业组织机构，接受最新的技术，同时他也对建筑设计和施工的方面表现出兴趣、关注和领导力，曾志愿参与过关岛、夏威夷、萨摩亚、海地和尼泊尔等地区的地震灾区工作。

Anantha Chittur
Senior Associate | 高级副总
Baldridge & Associates Structural Engineering, Inc. (BASE)
BASE结构工程公司
Chicago, USA | 芝加哥，美国

Anantha Chittur has over a decade of experience designing and peer reviewing a wide variety of structures, ranging from sports and retail facilities to high-rise and mixed-use buildings involving structural steel, cast-in-place, pre-cast, and post-tensioned concrete. He has been involved in 16 high-rise projects, all of which were located in areas of high seismic activity – namely India and Hawaii. Chittur leads BASE's Chicago office and also oversees the firm's work in India. He is responsible for project management, structural design, construction administration, and business development.

Chittur先生拥有超过十年的设计和同行评议经验。他的同行评论经验来源于多样的项目，项目类型涉及从体育和零售设施到高层建筑，还包括混合功能的钢结构、现浇、预制和后张混凝土的结构类型的建筑。他参与过16个高层项目的设计，这些项目均位于印度和夏威夷等高地震区。他是BASE公司芝加哥办公室和海外印度公司的领导者。Chittur先生负责项目管理，结构设计，施工管理和商业开发。

Abstract | 摘要

Located adjacent to China, the Indian Subcontinent is also experiencing amazing concentrated urban growth facilitated in part by high-rise commercial and residential construction. These new projects are often of a magnitude and complexity unimaginable even a few decades earlier by the planners, designers, building authorities, and code writers responsible for assuring public safety; however, much of this work is based on traditional, but unfortunately outdated, construction methods and building codes. The recent earthquake that struck Katmandu, Nepal brought to light some of the shortcomings of such building approaches. Many of the newly constructed high-rises in Katmandu suffered irreparable damage that made the buildings unusable. Is this to happen in more densely populated cities in India, Pakistan, and Bangladesh, resulting in a greater loss of life and impact on society? This paper will discuss the current risks and impediments to change in the design and construction of structures in places of seismic activity.

Keywords: Building Codes, Construction Practices, India, Safety, Seismic, Tall Buildings

毗邻中国，印度次大陆正在经历惊人的城市集中增长，高层商业建筑和住宅建设在一定程度上促进了这一增长。这些新项目往往有庞大的规模和具有的复杂性，这是几十年前的规划师、设计师、建筑主管部门和保证其安全性的建筑规范编写者都未曾想到的。这些作品中的大部分使用着基于传统但已过时的施工方法和建筑规范。 最近在尼泊尔加德满都发生的地震暴露出了这些建筑在设计和施工方法上的缺点。在加德满都，许多新建的高楼遭到了建筑无法使用的程度的破坏。如果这样的惨剧发生在印度、巴基斯坦和孟加拉国这些人口更密集的城市，是否将造成更惨痛的生命损失，对社会产生更大的不利影响呢？ 本文将讨论当今的设计和施工中存在的风险和需要克服的阻碍。

关键词：建筑规范、施工实践、印度、安全、地震、高层建筑

Introduction

Megacities, with their increased population densities, require special attention to city planning and enhanced building safety. This paper illustrates how long-standing customs and construction methods can be an impediment to building safety, and suggests areas for improvement.

Located adjacent to China, the Indian Subcontinent is also experiencing amazing concentrated urban growth facilitated in part by high-rise commercial and residential construction. These new projects are often of a magnitude and complexity unimaginable even a few decades earlier by the planners, designers, building authorities, and code writers responsible for assuring public safety; however, much of this work is based on traditional, but unfortunately outdated, construction methods and building codes.

The recent earthquake that struck Katmandu, Nepal brought to light some of the shortcomings of such building approaches (Figure 1). Many of the newly constructed high-rises in Katmandu suffered irreparable

引言

巨型城市随着人口密度的增长，需要特别关注城市规划和提高房屋建筑的安全。本文阐述了长期的习惯和施工方法是如何阻碍施工安全，把更多的人处于危险之中，并且提出了需要改进的地方。

毗邻中国，印度次大陆正在经历惊人的城市集中增长，高层商业建筑和民用住宅建设在一定程度上促进了这一增长。这些新项目庞大的规模和具有的复杂性，是几十年前的规划师、设计师、建筑主管部门和建筑规范编写者从未想到的。现在所使用的施工方法和建筑规范的大部分是基于传统的，但不幸的是过时的。

在尼泊尔加德满都最近发生的地震，暴露出了一些建筑设计和施工方法的缺点（图1）。在加德满都的许多新建的高楼都遭到了破坏，使得一些建筑无法使用（图2）。如果这样的惨剧发生在印度、巴基斯坦和孟加拉国的人口更密集的城市，是不是将会造成更多的生命损失和对社会产生极大的不利影响？

在2013年9月提交给印度国家灾害管理局的建筑地震易损性评估报告指出了类似的担忧：

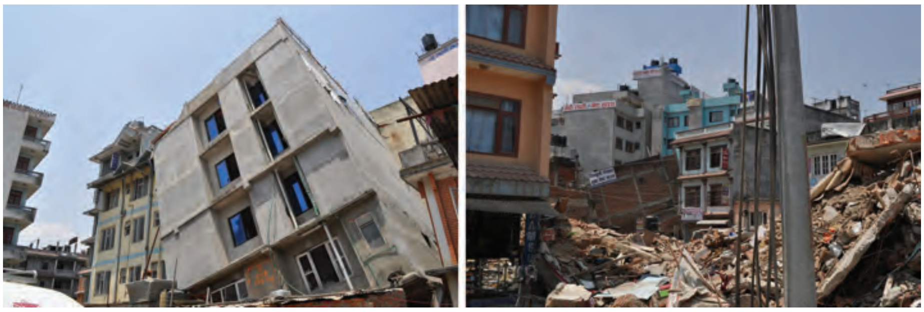

Figure 1. Earthquake damage in Kathmandu, Nepal (Source: BASE)
图1. 尼泊尔加德满都的地震破坏（来源：BASE结构工程公司）

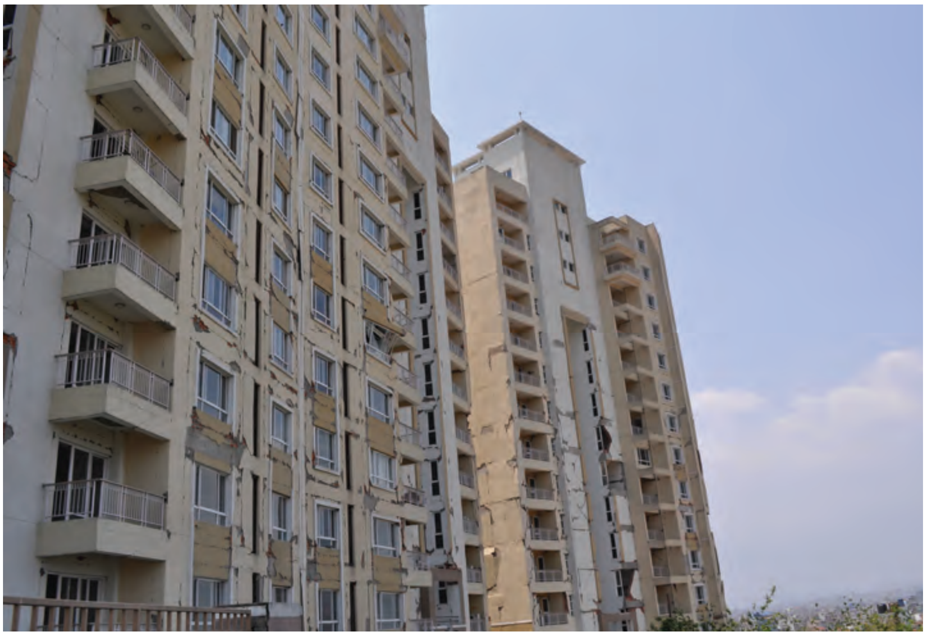

Figure 2. Earthquake damage to a modern apartment building in Kathmandu, Nepal (Source: BASE)
图2. 尼泊尔加德满都的新建公寓楼遭受地震破坏（来源：BASE结构工程公司）

damage that made the buildings unusable (Figure 2). Is this to happen in more densely populated cities in India, Pakistan, and Bangladesh, resulting in a greater loss of life and impact on society?

The Seismic Vulnerability Assessment of Building Typologies in India, submitted to the National Disaster Management Authority of India in September 2013, noted similar concerns as follows:

The past few decades have witnessed an increase in the number of damaging earthquakes in India, with ten damaging earthquakes occurring during the last two decades itself. The vast extent of damage and the consequent loss of life associated with these events reflects the poor construction practice in India. Before the 2001 Bhuj earthquake, constructions with poor seismic resistance were assumed to be a feature of non-urban areas, with urban structures considered safer due to the use of engineering knowledge and modern construction materials; however, this earthquake shattered the myth of urban seismic safety through widespread damage to modern buildings. The low awareness among the general public towards structural safety and the inability of regulatory bodies and technical professionals in maintaining quality standards in constructions has created an urgent need to educate the leaders, public, city planners, architects, and engineering professionals about the consequences of earthquakes (Seismic Vulnerability Assessment Project Group, 2013, p.vii).

Current risks and impediments to change in the design and construction of buildings in this region are discussed in detail, including:

- Comparisons of international codes and standards;
- Examples of improvements already underway; and,
- Suggestions for a path forward that advances overall building safety

Comparisons of International Codes and Standards

The comparisons noted in this paper are between the International Building Code (IBC), developed in the US and used internationally, and current Indian

在过去的几十年里发生在印度的破坏性地震的数量有所增加，在过去的二十年里就发生十起破坏性地震。影响巨大的损害和生命的损失反映了印度比较差的施工水平。 在2001年印度普杰地震发生之前，普遍认为非城市区的建筑结构的抗震施工质量比较差， 而城市中由于使用了土木工程知识和现代化的建筑材料而被认为具有比较安全的建筑结构。然而，此次地震中的现代建筑的广泛破坏说明现阶段的城市建筑的抗震性能是很差的。公众对于结构安全的认知度通常是比较低的，政府监管机构和专业技术人员在保证施工质量上的能力是不够的，所以现在迫切需要让政府的领导者、普通民众、城市规划师、筑师和工程专业人员深入了解地震的后果 （地震易损性评估项目组，2013年，页数vii）。

针对这个区域的建筑物的设计和施工的改变而引起的风险和障碍进行了详细的讨论，其中包括：

- 现行规范和国际上的规范的比较；
- 找到已经提高结构安全的工程实例；
- 为推进全面建筑安全指明方法和途径。

现行规范和国际上的规范的比较

在这篇文章中提到是国际建筑规范和现行的印度规范的比较，国际建筑规范是由美国提出并且在全世界广泛使用的规范。需要特别注意的是所有的建筑规范在内容和方法上都或多或少有一些固有的缺陷，因此，不能简单的说一个规范一定优于其它规范。但是一些经验教训是可以通过这些比较而得知的。

在美国一个经常性的问题的挑战是，国际建筑规范每三年会更新一次，这就导致在每一个更新周期中没有留下足够的时间进行审核和学会使用新的条文。现实中就有几个这样的实例，比如一个条文在三个更新周期中从严格到不严格再到严格。这里有两个例子包括：在2002年的规范中提高了后张预应力混凝土双向板的最大容许拉力值，但是在2005的规范中这一值又降到了和1999年规范一样的值；在1998年的规范中去掉了滨海结构的高风暴露D的种类，但是在2010年的规范中又恢复了。

而另一方面，印度的规范，特别是抗震设计可追溯至2002年。根据印度结构抗震设计规范IS 1893（第一部分），情况更严重的是印度2002年的抗震设计规范借鉴了美国1991年到1994年的规范：2002年印度抗震规范规定：

在这个规范的制定过程中，由于各个国家的实际情况存在一定的差异，所以针对这

Standards. Each building code has some inherent flaws, both in content and process, and there are lessons that can be learned by these comparisons.

In the US, a problematic challenge is that its primary building code, the IBC, is updated every three years, leaving insufficient time to vet and learn to use new code provisions introduced in each code cycle. There have been several instances where code provisions have gone from stringent to less stringent, and back to stringent, over code cycles. Two examples of this include: increasing maximum allowable tension stresses in post-tensioned concrete slabs in 2002, and then decreasing it back to the 1999 values in 2005; and eliminating high wind exposure D for oceanfront structures in 1998, and reintroducing it in 2010.

On the other hand, the Indian Standards, particularly those for seismic design, date back to 2002. To make matters worse, these standards draw references from US standards and codes from 1991 and 1994 as noted in the Indian Standard Criteria for Earthquake Resistant Design of Structures IS 1893 (Part 1) – 2002, which states:

In the formulation of this standard, due consideration has been given to international coordination among the standards and practices prevailing in different countries, in addition to relating it to the practices in the field in this country. Assistance has particularly been derived from the following publications:

- a) UBC 1994, Uniform Building Code, International Conference of Building Officials, Whittier, California, USA1994.
- b) NEHRP 1991, NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part 1: Provisions, Report No. FEMA 222, Federal Emergency Management Agency, Washington, DC, USA, January 1992.
- c) NEHRP 1991, NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part 2: Commentary, Report No. FEMA 223, Federal Emergency Management Agency, Washington, DC, USA, January 1992.
- d) NZS 4203 : 1992, Code of Practice for General Structural Design and Design Loadings for Buildings, Standards Association of New Zealand, Wellington, New Zealand, 1992 (Bureau of Indian Standards, 2007, p.4).

While it is difficult to say what the appropriate code cycle should be, it is obvious that the seismic provisions of the Indian Code, based in part on 1990's versions of US standards, have missed out on code improvements that are based on lessons learned in post-earthquake damage assessments. Since the UBC 1994, the standards in the US have been updated seven times with significant revisions and improvements to the seismic provisions in four of these updates.

Inconsistent Application of Building Code

The review of numerous projects throughout India found two building code provisions that seemed to have inconsistent application across these projects. The first deals with the fire and life safety provisions of the National Building Code of India, which notes the following objectives:

The design of any building and the type of materials used in construction are important factors in making the building resistant to a complete burn-out and in preventing the rapid spread of fire, smoke, or fumes, which may otherwise contribute to the loss of lives and property (Bureau of Indian Standards, 2005, p.14).

High-density urban developments must be designed to ensure life safety in the event of fire. The code describes four "Type(s) of Construction" based on Occupancy Classification and Comparative Floor Area Ratios" with Type 1 being the most stringent; however, many high-density residential and mixed-use projects in India are designed using a less stringent Type 2 construction that provides a lower fire resistance rating.

The second provision often inconsistently applied is the calculation of the fundamental natural period of vibration of a building. This is an important variable used to determine the seismic forces applied to a building. Figure 3 is the empirical expression included by the Indian Standard 1893 to estimate this (Bureau of Indian Standards, 2007, p.24).

Some local engineers opine that this code provision is mandatory, while others, since the code notes "may be estimated by," use computer analysis coupled with limits contained in the US codes to determine the building time period, which is one of the most critical seismic design parameters.

The older empirical approach based on ATC3-06, originally written in 1978, calculated the time period based on the base dimension of a building. There is a large scatter between measured time periods and

样的情况，一些辅助性的信息可以从下列出版物中得出：

- a）统一建筑规范1994，作者是1994年美国加利福尼亚州国际建筑会议的官员惠蒂尔。
- b）国家地震减灾计划1991，关于新建筑的抗震推荐条例，第1部分：条文，报告号：FEMA222，美国联邦紧急事务管理署，出版于1992年一月的美国华盛顿特区。
- c）国家地震减灾计划1991，关于新建筑的抗震推荐条例，第2部分：条文解释，报告号：FEMA223，美国联邦紧急事务管理署， 1992年一月的美国华盛顿特区。
- d）新西兰规范4203：结构设计及建筑物设计荷载规范，该规范是由新西兰标准协会于1992年在新西兰首都惠灵顿出版的（印度标准机构，2007年，第4页）。

虽然现在很难确定适当的规范更新周期是多久，但是很明显，基于美国上世纪九十年代的规范的印度现行的抗震规范，确实已经错过了很多震后损失评估的经验教训的更新。自1994年美国统一建筑规范首次出版以来，已经经历了七次显著修订和四次抗震规范的更新。

建筑规范的规定和使用的不一致

在印度的许多项目的审查中发现，建筑规范在这些项目中应用是不一致的。第一个是在印度国家建筑规范中关于消防和生命安全规定的：

任何建筑物的设计和施工所用材料的类型是建筑阻燃、防止火灾和烟雾迅速蔓延的重要因素之一，如果不加以重视，很有可能会造成生命和财产的损失（印度标准机构，2005年，第14页）。

高人口密度的城市的建设需要进行设计，以确保一旦发生火灾后的生命安全。这条规范描述了四个施工种类，主要是基于占用分类和比较楼板面积比，其中种类一是最严格的建筑施工。然而，在印度许多高密度住宅和综合用途项目中使用的是较宽松的具有较低耐火等级的第二种类型的建筑施工。

该规范描述了四个基于占用分类和比较楼板面积比的施工分类，其中种类一适用于最密集或风险最高的建筑，因此具有最严格的防火要求。在印度，高入住率的项目即使应该使用第一种类型的建筑施工，但是开发商和设计团队都倾向于使用不太严格的第二种类型。

7.6.2 The approximate fundamental natural period of vibration (T_a), in seconds, of all other buildings, including moment-resisting frame buildings with brick infil panels, may be estimated by the empirical expression:

$$T_a = \frac{0.09\,h}{\sqrt{d}}$$

where

h = Height of building, in m, as defined in 7.6.1; and

d = Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

Figure 3. IS 1893 Seismic Equation for building period of vibration (Source: Bureau of Indian Standards)
图3. 印度IS 1893规范中建筑自振周期的计算公式（来源：印度规范制定机构）

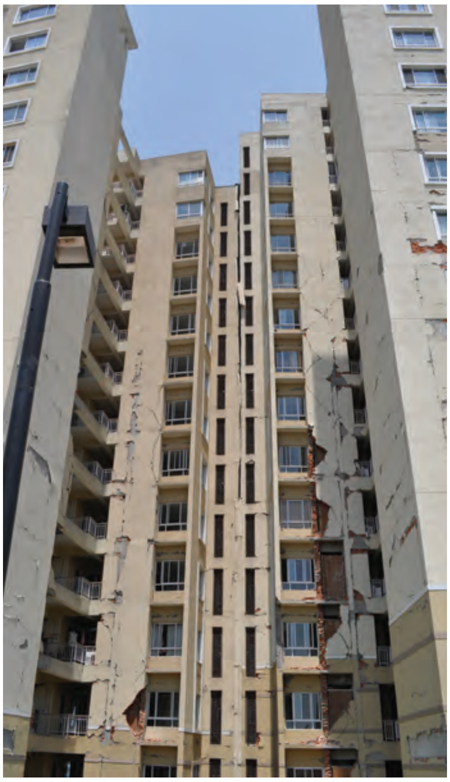

Figure 4. Narrow seismic separation joint (Source: BASE)
图4. 狭窄的抗震缝（来源：BASE结构工程公司）

time period calculated using this formula on shear wall buildings (as reported by Goel et. al), which resulted in its abandonment by the US codes some 20 years ago. This empirical approximation significantly overestimates forces for low-rise structures and underestimates forces for high-rise structures. This equation was revised in UBC 97, which also included many other significant updates based on post-earthquake damage assessment after the 1994 Northridge earthquake in the US.

As this expression is based on the base dimensions of a building, designers often modify these dimensions by introducing seismic separation joints. This has the adverse effect of reducing the seismic redundancy and capacity of the original building configuration without a joint. This older version of the seismic code also underestimates the required width of this joint. This may lead to a gap that is too narrow, and the buildings can pound against each other in an earthquake (Figure 4).

Dangers of Unreinforced Brick and Block

One of the most dangerous building materials in high-seismic zones is unreinforced masonry, both brick and block, especially when used as a load bearing material. Even when used as non-load bearing partitions, unreinforced masonry can create multiple dangers including, but not limited to the following:

1. Creating falling debris outside and inside of a building, which is particularly risky with unreinforced parapets and freestanding walls (Figure 5).

另一个关于规范的不一致是建筑物的振动的基本固有周期的计算。这是用于确定建筑物地震力和抗震设计重要参数的。图3是印度规范IS 1893用于估计这一数值的经验公式（印度标准机构，2007年，第24页）。

在印度一些地方的工程师们认为，该规定是强制性的，而其他的一些工程师，因为规范注释写到“可以通过估算”，所以使用计算机进行分析，加上一些包含美国规范的限制条件，以确定建筑的周期，这是最关键的抗震设计参数之一。

旧的经验公式计算建筑物的周期是基于建筑的尺寸，这种方法称为ATC3-06，最初写于1978年。对于剪力墙体系的建筑，戈埃尔发现实际测量出的建筑物的周期和基于经验公式计算出来的周期具有很大差异，这直接导致这种方法在大约20年前在美国被弃用。这种经验公式过大估计了低层建筑的地震力，而过低估计了高层建筑的地震力。这个经验公式在UBC97中进行了修改，这一修改是基于美国1994年北岭地震后损失评估的重要更新。

因为这个经验公式是基于建筑物的基底尺寸的，设计者经常通过引入抗震缝来修改这些尺寸。这具有减少地震冗余和结构抗震能力的不利影响。这个比较旧的抗震规范还低估了抗震缝所需的宽度。这可能导致太窄的抗震缝间隙，建筑物在地震时彼此可能发生撞击（图4）。

无配筋的砖块和砌块的危险

在地震高发区，无配筋的砌体是最危险的建筑材料之一，当砖块和砌块作为承重材料使用时尤其如此。即使作为非承重的填充材料，无配筋的砌体也会发生很多危险情况，包括但不限于：

1. 在建筑物的外部和内部可能产生坠落的碎片，尤其是无配筋的屋顶矮墙和悬臂墙的风险是很大的（图5）。
2. 潜在的阻断紧急出口通道（图6）。
3. 增加地震质量和地震力。

填充砌体可以改变结构的抗震性能。例如，常见的建筑结构在首层大厅和停车场都有开放的空间，上部都有砌体结构填充墙，这有可能会造成首层成为地震薄弱层。

随着时间的推移，国际建筑规范已通过限制或禁止使用无配筋的砌体结构而解决了这些危险。即使当填充的砌体结构中使用了钢筋，也对建筑的抗震性能没有太多改变，例如：

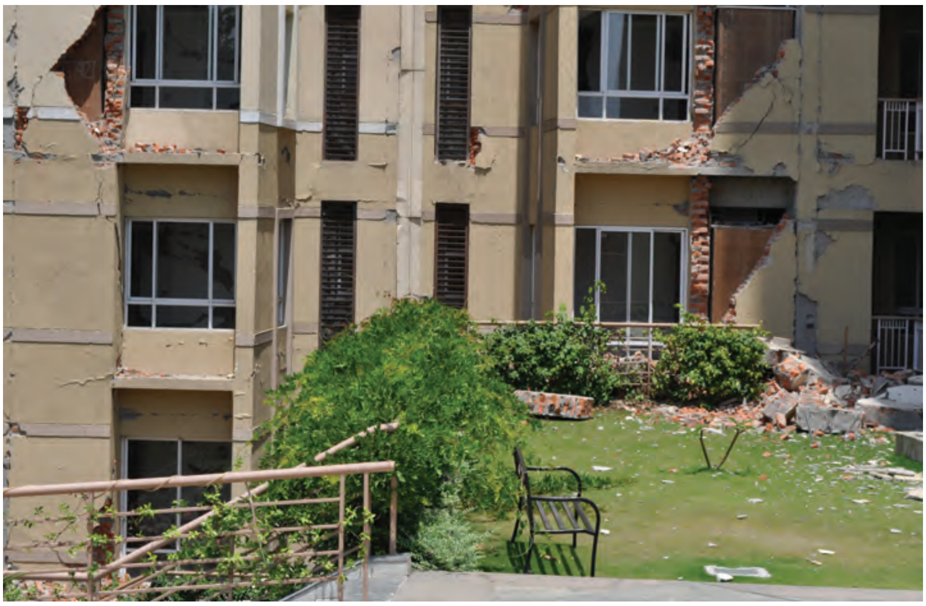

Figure 5. Masonry debris around the building exterior (Source: BASE)
图5. 建筑外立面周边的砌体碎片（来源：BASE结构工程公司）

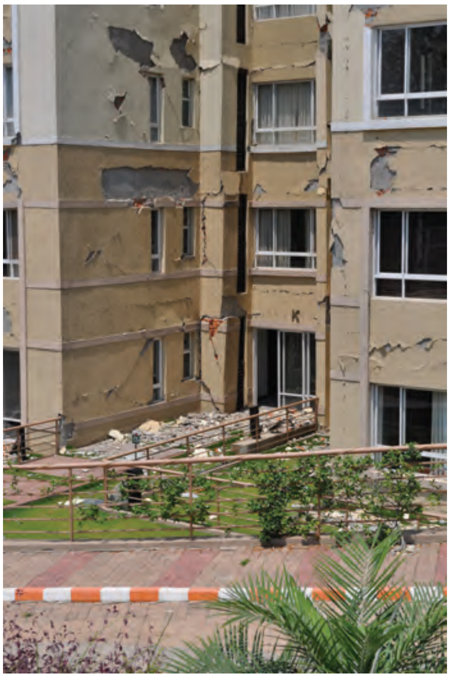

Figure 6. Masonry debris near the building exit, including precariously leaning masonry shaft wall (Source: BASE)
图6. 临近建筑物出口的不安全的砌体管道井和砌体碎片（来源：BASE结构工程公司）

2. Potential for blocking emergency egress pathways (Figure 6).
3. Increasing the seismic mass, and subsequently, forces on a structure.

Infill masonry can change the seismic performance characteristics of a structure. For example, a common building configuration may have open spaces at the ground level for lobbies, parking, and/or services with stiff infill brick façades above. This has the potential to create a seismically dangerous soft story.

Over time, international codes have addressed these dangers by restricting and/or prohibiting the use of unreinforced masonry. Even when masonry is reinforced the codes are careful to ensure that infill masonry does not change the seismic performance of a building, for example:

IBC 2106.3.1 Masonry walls not part of the lateral-force-resisting system.
Masonry partition walls, masonry screen walls and other masonry elements that are not designed to resist vertical or lateral loads, other than those induced by their own mass, shall be isolated from the structure so that the vertical and lateral forces are not imparted to these elements. Isolation joints and connectors between these elements and the structure shall be designed to accommodate the story drift (International Code Council, 2006, p.399).

While the Indian Seismic Standard notes in its Forward, "In highly seismic areas construction of a type which entails heavy debris and consequent loss of life and property, such as masonry, should preferably be avoided," (Bureau of Indian Standards, 2007, p.3) unreinforced masonry to this day remains the predominant building material for partitions, including emergency exits such as stairwells, in Indian construction (Figure 7). The Indian Standards may actually be perpetuating the use of infill masonry by including it in seismic code equations, such as noted in Figure 3.

Unnecessary Building Weight is your Enemy

Following Newton's second law of motion, the seismic forces a structure must be designed for, as calculated by building code formulas,

Figure 7. Un-reinforced masonry exit stairwell (Source: BASE)
图7. 无配筋的砌体楼梯的出口井道（来源：BASE结构工程公司）

IBC2106.3.1 砌体墙不能作为建筑抗侧力体系的一部分。
砌体隔墙，砌体屏幕墙和其他砌体不能被用来承担竖向力和侧向力，这些砌体结构需要和主要承重构件隔离开来，以使竖向力和侧向力不施加于这些构件上。砌体结构和承重结构之间的隔离接头和连接器的设计应满足层间位移（国际规范委员会，2006年，399页）。

而印度地震规范注意到它的变化，“在地震高风险地区，可能产生大量碎屑和可能造成人民生命财产损失的建筑类型，如砌体结构，最好避免使用，”（印度标准机构，2007年，第3页）

不必要的楼层重量是你的敌人

根据牛顿第二定律，基于规范的地震力的设计值和建筑结构的质量成正比。因此建筑物越重，在地震中建筑物将承受越大的地震力。基于这个原因，不必要的建筑重量是建立一个地震弹性结构的敌人。

在印度的建筑物比在世界其他地方的要重。这主要是由于可能被认为是不必要的“重楼”的方法造成的，如：

1. 为了解决混凝土面层的低质量问题，在诸如停车区域暴露的混凝土板通常具有一个次级3英寸（75毫米）厚混凝土面层。该面层使得混凝土板的自重增加20%到30%，并经常要使混凝土地板加厚10%。
2. 为了解决混凝土水平度的低质量问题，在住宅和商业建筑地板上通常会加3英寸（75毫米）厚面层。为了提供弹性，即使是轻质的木地板，在设计中也会使用重的水泥砂浆和石材饰面。一些装饰材料，要达到一个适当的光洁度，面层最多可以减少到1英寸（25毫米）至2英寸（50mm）。相比一些更实际的情况，这些增加的重量也会使楼板重量提高5%到10%。
3. 填充砌体墙对提高建筑质量的影响最大。在商业建筑中，相比于更轻的立柱墙，填充砌体墙将导致重量的显著增加。在住宅建筑中这种增加效应会更加显著。
4. 为了解决一个低质量的管道安装，而且与其他专业的协调工作往往在设计阶段是无法完成的，潮湿的地方如浴室，厨房和阳台会做低6到12英寸（150至300mm），然后用砖或砌块瓦砾和水泥砂浆进行回填。在这些区域中的结构的重量很容易达到正常结构的两倍。这种做法，遗憾的是，很难达到预期的效果。在阳台中下沉式板经常使用，因为没有人在设计过程中协调

Figure 8. Thick rubble fill at balcony (Source: BASE)
图8. 阳台上的碎石填充层（来源：BASE结构工程公司）

Comparison of Indian and US Standards for Building Loads		
Live Loads		
Item	**IS 875 (Part 2) (kN/m²)**	**IBC (kN/m²)**
Office (Typical)	4.0 (with storage)	2.5
	2.5 (no storage)	--
Office (Corridors)	4.0	5.0
Residential (Units)	2.0	2.0
Residential (Corridor)	3.0	2.5
Vehicle Barriers	Not specified	26.7kN
Superimposed Dead Loads		
Item	**India (kN/m²)**	**US (kN/m²)**
Floor Finishes	1.5 to 2	0.5 to 0.75
Ceiling and Services	0.5	0.5
Partition Walls	2.5	1.0
Sunken Areas (balcony, toilets)	2.0 to 3.0	--

Figure 9. Comparison of Indian and US Standards for Building Loads (Source: BASE)
图9. 印度和美国规范建筑荷载的比较（来源：BASE结构工程公司）

are directly proportional to the weight of the building; therefore, a heavier building will have higher forces in an earthquake. For this reason, unnecessary building weight is your enemy when trying to build a seismically resilient structure.

Buildings in India are substantially heavier than those in other parts of the world. This is primarily due to what might be considered unnecessary "heavy building" approaches, such as the following:

1. Intended to address a lower quality of concrete finishing, exposed concrete floors in areas such as parking decks will often have a secondary three-inch (75-millimeter) finishing screed of concrete. The weight of this secondary screed can increase the dead weight on a floor by 20 to 30 percent, and often requires the thickening of that floor by 10 percent.
2. Intended to address a lower quality of concrete levelness, finished floors in residential and commercial buildings typically specify a finish material of three inches (75 millimeters) as well. To provide flexibility even when lighter wood flooring is anticipated, the weight used in design is for heavier grout and stone finishes. While it can be said that some finish material should be anticipated, an appropriate finish could be reduced to one inch (25 millimeters) to two inches (50 millimeters) maximum. The weight of this additional thickness compared to something more practical can increase the weight on a floor by five to 10 percent.
3. Infill masonry partitions can have the biggest impact on increasing building weight. In commercial buildings, this creates a significant additional weight compared to lighter stud-wall framed partitions. In residential buildings, the penalty is even higher.
4. Intended to address a lower quality plumbing installation and to simplify coordination between trades, wet areas such as bathrooms, kitchens, and balconies are often sunken by six to 12 inches (150 to 300 millimeters) and then filled back with brick or block rubble and grout. The weight of the structure in these areas is easily twice that of normal structures. This practice, unfortunately, rarely achieves the intended result as a plumbing leak, as in a sunken slab area, it will only be discovered in the ceiling of the unit below. In balconies, a sunken slab is often used to avoid drainage coordination during design. The final product ironically is often a flat finish with no slope to drain built on two layers of heavy materials: the supporting structure and heavy sunken slab infill (Figure 8).

In a comparison of building weight for residential buildings, the Indian structure is easily 50 to 75 percent heavier than the US building (Figure 9). While one might think a heavier building is better, this is not the case

排水。最终做法通常是在两层较重材料上的加没有斜率的面层：支撑结构和下沉重板的填充结构（图8）。

就住宅类建筑的构件重量而言，印度的建筑物通常比美国的建筑物（图9）重50%至75%。虽然人们可能会认为较重的建筑物比较好，如果这个重量差的大部分是结构自重的话，这对结构的安全性方面不能提供任何好处。这额外的重量也违背可持续发展和绿色建筑的原则。

缺乏独立的施工质量控制

国际建筑规范用了整整一章（第17章结构测试及特殊检查），来讲述独立的质量控制过程。这些要求的加入被纳入1988年版的统一建筑规范，这是国际建筑规范的前身规范之一。

本节的加入是在美国的建筑结构失效，而导致个人悲剧和巨大的财产损失之后。美国结构工程师联盟的报告：

在1982年8月美国众议院下属委员会针对结构倒塌的调查研究和监督举行了听证会。基于这些听证会，委员会形成了标题为公共设施结构失效的科学和技术报告，该报告的编号为众议院报告98-621，并于1984年3月提交给了第98届美国国会。委员会查明的结构失效的两个最重要的因素是：

Figure 10. Non-conforming seismic ties at project site (Source: BASE)
图10. 施工现场不符合规范要求的抗震箍筋接头（来源：BASE结构工程公司）

if the majority of this weight differential is dead weight providing no structural benefit. Gravity can be very unforgiving and the more of it there is, the less forgiving it becomes. This additional weight also goes against the tenets of sustainable, green buildings.

Lack of Independent Construction Quality Control

The IBC devotes an entire chapter (Chapter 17 Structural Tests and Special Inspections) to the process of independent quality control. These requirements were incorporated into the code in the 1988 Edition of the Uniform Building Code – one of the predecessor codes to the IBC. The addition of this section stemmed from structural failures in the US that resulted in personal tragedies and tremendous property damage costs. The Coalition of American Structural Engineers reported:

In August 1982, investigative hearings were held by the US House of Representatives Subcommittee on Investigations and Oversight to examine the causes of structural failures. Based on these hearings, The Committee on Science and Technology's report, titled Structural Failures in Public Facilities, House Report 98-621, was presented to the 98th U.S. Congress in March 1984. The two most critical factors identified by the Subcommittee are:

- a) Need for improved organization of construction projects and better communication between the participants.
- b) Need for construction inspection by the Structural Engineer of Record (SER) during the construction of principal structural elements" (Coalition of American Structural Engineers, 1994, p.1).

The Subcommittee noted that, "For a variety of reasons, the structural engineer of record or his designee is often not present on the job site during the construction of principal structural components; the absence of structural engineer has permitted flaws and changes on site to go unnoticed and uncorrected" (Coalition of American Structural Engineers, 1994, p.1). In addition, the Subcommittee recommended that every effort should be made, "to ensure that provisions are written into building codes and adopted in public forum which make the on-site presence of the structural engineer mandatory during the construction of structural components on public facilities" (Coalition of American Structural Engineers, 1994, p.1).

One example is the mis-installation of a critical seismic detail, providing a closed tie with bar ends hooked into the core of a column. This detail, which is clearly indicated in Indian Standards and construction documents, is often missed on the job site (Figure 10). Independent inspections may catch this.

Blind Reliance on Computerized Design

The advent of user-friendly structural analysis programs, combined with complexities in modern buildings and accelerated project schedules, have rendered computers often a necessity and an important tool at the engineer's disposal. However, "with great power comes great responsibility," and the onus is on the engineer to prevent garbage in, garbage out: the potential that a computer, operating by logical algorithms will unquestioningly process unintended, even nonsensical, input data ("garbage in") and pro-duce undesired, often nonsensical, output ("garbage out"). The engineer must ensure the fundamentals of building behavior and design are accurately captured in their computer analysis through simplified hand calculations or spreadsheets and a bit of common sense and engineering judgment.

While this list is not intended to be exhaustive, it outlines important structural design requirements that are often overlooked.

- a）需要改进建设项目的组织结构和项目参与者之间的沟通。
- b）在主要结构构件的施工工程中，需要由结构工程师在施工现场进行检验（美国结构工程师协会，1994年，第1页）。

委员会指出，“由于多种原因，结构工程师或其指定的人在主要结构构件施工期间是无法出现在施工现场的。由于结构工程师的缺席将会导致在施工现场被忽视和未修正的缺陷和变化。”（美国结构工程师协会，1994年，第1页）。此外，委员会还建议，应尽力做到“保证规范条文写入建筑规范，并且让公众了解，使结构工程师在公共设施的建设过程中进行现场监督做为强制性规定而被采纳。”（美国结构工程师协会，1994年，第1页）。

一个例子是框架柱的加密区闭合箍筋的错放，通常情况下抗震的闭合箍筋的端头要深入到柱子里面一定的长度。这个抗震构造措施，印度规范和施工文件都明确表明了正确做法，但是在施工现场往往会放错（图10）。独立的现场检查可能会避免这一错误。

对计算机设计的盲目依赖

随着现代建筑物越来越复杂和人性化的结构分析程序的出现，以及加快了的项目进度，使得计算机成为工程师必须的重要的工具。但是，“能力越大，责任越大”，而工程师要负起责任，防止垃圾信息输入电脑程序，从而输出垃圾信息，一台电脑的潜在能力是用逻辑算法操作的，它是没有想法和意识的，输入怎样的数据，就会得到相应的输出结果。工程师必须确保计算机的分析模型准确的知悉了建筑物的基本特性行为和设计，这可以通过简单的手工验算和工作表格进行工程判定。

虽然此列表并不意在穷举，但它概述了常常被忽略的重要的结构设计的要求。

1. 隔板设计：隔板作为侧向力传递路径的重要组成部分，电脑程序通常是没 有内置的模块来进行检查和设计的。在一些特定的部分隔板设计是需要特别关注的，比如隔板不连续的区域，凹进去的角落，大开洞的楼板，比主要隔板窄很多的走廊和连接桥等。
2. 水平支撑杆件：建筑物的侧向力需要通过隔板传到剪力墙上。在很多情况下，剪力墙的核心区域正是建筑物的外部轮廓，通常核心区的边缘都有机电和水管的管道。所有这些情况必须要对隔板进行检验，并在关键区域增 加水平支撑钢

1. Diaphragm design: These elements function as a critical part in the lateral force load path but computer programs do not have in-built modules to design them. Some areas to carefully consider are designing diaphragm discontinuities, re-entrant corners, large openings in slabs, corridors/link bridges which are narrower than the main diaphragm, etc.
2. Drag struts: Lateral loads need to be delivered to shear walls through the diaphragm. Often the core is provided outside the footprint of the slab to maximize floor area, or there are mechanical and plumbing shafts on the sides of core walls. These situations necessitate additional checks on the diaphragm and provide "drag" reinforcement to ensure the loads can be adequately transferred from the diaphragm to the shear walls.
3. Use of rigid versus semi-rigid diaphragms: While a rigid diaphragm assumption is adequate for a majority of concrete structures, floors at which there are major changes in building stiffness should be carefully evaluated and provided with semi-rigid diaphragms that accurately capture the in-plane stiffness of the slab and associated forces on the shear walls.
4. Non-standard load path: In buildings where columns, slope, transition in shapes or size, and where centerlines are non-coincident, horizontal forces and/or eccentricities are introduced, resulting additional forces and movements in the columns and the floor slab/beam connecting them. Analysis simplifications assume nodal coincidence and these forces and eccentricities are not accounted for in analysis.

It is also crucial to note the importance of understanding load paths in reinforcing: in the end, if the reinforcing steel is not detailed for the forces that might occur, you may not get the desired results (Figure 11).

Lack of Robust Professional Support Organizations / Continuing Education

Due to both the frequency of building code changes and the increased complexity of the US codes, problems occur with misinterpretation or misuse of outdated code provisions by design professionals. Many projects in the US that result in some form of litigation have nothing to do with an actual failure of a system, but rather a lack of full compliance with new code provisions. For this and other reasons, the need for continuing education of design professionals to keep up with building code evolution was recognized. The professional licensing boards in many US states require a minimum amount of continuing education to maintain a professional license to practice engineering. This developed into a sub-

Figure 11. Balcony failure due to poor design detailing (Source: Dimitris Nikolopoulo)
图11. 阳台由于低质量的细部设计倒塌（来源：Dimitris Nikolopoulo）

筋，以确保水平荷载可以从隔板充分传递到剪力墙。

3. 刚性隔板和半刚性隔板的使用：尽管大部分混凝土结构都满足刚性隔板假定，但是在楼板刚度发生较大变化的地方需要认真评估，并且半刚性隔板准确捕捉楼板的平面内刚度和剪力墙相关的力。
4. 非标准的荷载传递途径：建筑物中，在柱子和坡度形状和大小改变的地方以及中心线不重合的地方，水平力和偏心率会在柱子中和连接柱子的楼板和梁中引起的额外的力和弯矩。而在简化分析中，这些额外的力和偏心并没有被考虑。

同样至关重要的是要加强理解载荷传输路径的重要性。最后，如果钢筋的细节没有处理好，就不会得到预期的效果（图11）。

缺乏强大的专业支持机构/继续教育

由于美国建筑规范的变化频率和规范逐步增加的复杂性，规范条文的误解和错误使用过时的规范是设计专业人员经常出现的问题。在美国导致某种形式的诉讼的很多项目都不是结构系统本身出现失效，而是缺乏全面遵守新的规范条文。基于各种原因，需要设计师进行继续教育来跟上建筑规范的发展更新。美国许多州的专业资格理事会要求，工程师必须保证一定时间的继续教育才能进行专业资格的注册。这已经发展成为一个专业设计的分支产业，专业出版物、研讨会和网络研讨会都会教专业人员如何正确使用建筑规范。

如果把提供继续教育的机构和供应商的名单全部列出来会是很多的。从结构工程角度来看，仅着眼于非营利专业机构，主要的机构如下：

1. ACEC – 美国工程公司委员会
2. ASCE – 美国土木工程师协会
3. ASTM – 美国测试和材料协会
4. ATC – 应用技术委员会
5. CTBUH – 高层建筑与城市人居委员会
6. ICC – 地震工程研究所
7. ICC – 国际规范委员会
8. NCSEA – 结构工程师协会全国委员会

专业的行业组织：

1. ACI – 美国混凝土协会
2. AISC – 美国钢结构施工协会
3. AWC – 美国木结构委员会
4. AWS – 美国焊接协会

industry of design professionals dedicated to producing publications, seminars, and, more recently, webinars on how to correctly use building codes.

From a structural engineering standpoint (focusing solely on non-profit organizations), the primary groups offering continuing education include:

- ACEC – American Council of Engineering Companies
- ASCE - American Society of Civil Engineers
- ASTM – American Society for Testing and Materials
- ATC – Applied Technology Council
- CTBUH – Council on Tall Buildings and Urban Habitat
- EERI – Earthquake Engineering Research Institute
- ICC – International Code Council
- NCSEA – National Council of Structural Engineers Associations

And professional trade organizations:

- ACI – American Concrete Institute
- AISC – American Institute of Steel Construction
- AWC – American Wood Council
- AWS – American Welding Society
- CRSI – Concrete Reinforcing Steel Institute
- LGSEA – Light Gauge Steel Engineers Association
- PCI – Precast/Prestressed Concrete Institute
- PTI – Post-Tensioning Institute

This list might seem a little overwhelming, but the benefits of having an extensive and robust group of professional support organizations for design professionals cannot be understated.

In India, on the other hand, there is little, if any, opportunity for support, professional development, or continuing education related to Indian building codes and standards. For this reason, many Indian engineers are members of US organizations.

Improvements Already Underway

Fortunately there are a number of improvements that are occurring within both the design and construction industries in India, including the following:

1. Updating the Seismic Code Provisions: There is a draft document updating the Indian Standard Criteria for Earthquake Resistant Design of Structures IS 1893 that addresses many of the shortcomings of the outdated current edition. Hopefully, this document will be made official soon, along with some form of continuing education series to assist design professionals in learning and applying the new standard correctly.
2. Movement towards lighter-weight building materials: On larger projects, the use of lighter AAC block in lieu of heavy and brittle brick partitions is becoming more prevalent. The use of even lighter metal stud and drywall partitions are also finding their way into the market, and the use of lighter post-tensioned concrete slabs is also becoming more common.
3. Design and construction reviews: In many populated cities in India, there is little, if any, design review by municipal governments. Larger, more sophisticated developers, who see the value in being recognized for safe and high-quality products are initiating their own design review and construction quality programs.

Suggestions for a Path Forward in Improving Building Safety

Changing long-standing practices is never an easy process, but is critical to improving building safety in growing cities. Finding practical ways of implementing these changes is an important first step. The following are some suggestions:

1. Finalize the adoption of the updated seismic standards.
2. Prohibit the use of unreinforced masonry, if not completely, at least in and around stairwells and egress paths.
3. Supplement municipal reviews with other independent quality control programs. With the surge in new construction, municipal governments may not be able to handle this. Examples from the US include Special Inspection programs and municipally-approved, third-party design reviewers.
4. Strengthen the various Structural Engineers Associations of India so they can be a greater catalyst for raising the quality of the profession, provide extensive continuing education

5. CRSI – 混凝土钢筋协会
6. LGSEA – 轻钢工程师协会
7. PCI – 预制/预应力混凝土
8. PTI – 后张力混凝土研究所

这份名单似乎有点势不可挡，但庞大专业支持机构对设计专业人员的好处是不能否认的。

在印度，另一方面，与印度规范相关的专业支持、专业发展和继续教育的机构是很少的。基于这个原因，许多印度的工程师是美国专业组织的成员。

已经采取的改进措施

幸运的是，在印度包括建筑设计和建筑施工已经有了很大的提高，包括以下几点：

1. 更新抗震规范 — 印度规范制定机构针对结构的抗震设计规范IS1893提出了 一个草案，草案中解决了现有规范中的问题，并结合继续教育，以帮助设计专业人员学习和正确使用新的规范。
2. 使用质量较轻的建筑材料—在大型项目中，用较轻的蒸压加气混凝土代替较重的而且脆性的砖块变得越来越普遍。更轻的金属钉和石膏板隔墙都已经进入了市场，更轻的后张法预 应力混凝土板的使用也变得越来越普遍。
3. 设计和施工的审查 — 在印度许多人口众多的大城市几乎没有设计和施工审查机构，如果有的话，也是由市政府进行审查。一些从事庞大规模和复杂结构的开发商，看到了安全和高质量产品的价值，他们正在开始自己的设计审查和施工质量控制计划。

关于改善建筑安全的建议

改变长期存在的做法绝不是一个简单的过程，但在发展中的城市提高建筑安全是非常关键的。找到实现这些变化的实际方法是重要的第一步。下面是一些建议：

1. 确定采用最新的抗震规范。
2. 禁止使用无配筋的砌体结构，如果不能彻底弃用，至少在楼梯周边墙和出口路径上禁用。
3. 市政府机构结合其它独立的质量控制审查机制进行设计和施工审查。随着新建筑数量的激增，市政府机构可能无法处理众多的审查工

opportunities, and promote positive change in the construction industry.

5. Evaluate the best practices and systems already established in other countries, adapted for local conditions, to help implement improvements rapidly into the design and construction profession.

作。从美国的例子看，特殊审查机制和由市政府批准的第三方审查机构是需要引入的。

4. 加强印度的各种结构工程师协会，使他们能够成为提高行业专业品质的催化剂，并且能为工程师提供广泛的继续教育的机会，从而促进建筑行业的积极变化。

5. 评估其它国家已经建立的好的机制和体系，并结合当地的实际情况，制定出最佳的能迅速提高设计和施工品质的措施。

References:

Goel, R. (et al.) (1998). **Period Formulas for Concrete Shear Wall Buildings.** Virginia: American Society of Civil Engineers.

India. Bureau of Indian Standards. (2005). **National Building Code of India 2005.** New Delhi: Bureau of Indian Standards.

India. Bureau of Indian Standards. (2007). **Indian Standard Criteria for Earthquake Resistant Design of Structures: Part 1 General Provisions and Buildings.** New Delhi: Bureau of Indian Standards. (IS 1893 (Part 1) : 2002)

India. Seismic Vulnerability Assessment Project Group of IIT Bombay, IIT Guwahati, IIT Kharagpur, IIT Madras, IIT Roorkee. (2013). **Seismic Vulnerability Assessment of Building Types in India: Compilation of Catalogue of Building Typologies in India.** (s.l.): (s.n.).

International Code Council, Inc. (2006). **International Building Code 2006.** (s.l.): (s.n.).

US. Coalition of American Structural Engineers. (1994). **Case Commentary: The Special Inspection Process, Questions and Answers.** Washington D.C.: American Consulting Engineers Council.