Experience the Wenchuan Earthquake
——Structural Engineers' Point and View

Written By China Southwest Architecture Design & Research Institute Crop.Ltd.

来自汶川大地震亲历者的第一手资料

——结构工程师的视界与思考

中国建筑西南设计研究院有限公司(CSWADI)
冯　远　刘宜丰　肖克艰　等　著

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图书在版编目(CIP)数据

来自汶川大地震亲历者的第一手资料——结构工程师的视界与思考/中国建筑西南设计研究院有限公司冯远，刘宜丰，肖克艰等著.—北京：中国建筑工业出版社，2009
ISBN 978-7-112-10809-1

Ⅰ.来… Ⅱ.中… Ⅲ.地震灾害－概况－四川省－2008－摄影集
Ⅳ.P316.271-64

中国版本图书馆 CIP 数据核字（2009）第 034982 号

本书按建筑结构型式分类编著整理了砖混结构、框架结构、框架－剪力墙结构、高耸结构、厂房、网架等各类建筑结构的震损破坏情况，对砌体填充墙等围护结构、农村自建房、防震缝等震害，以及成都五城区的建筑震害和作者单位中国建筑西南设计研究院有限公司（CSWADI）在重灾区设计的各类建筑震害也进行了专章整理，内容翔实丰富，且从设计的视角去考量各类震害，更能结合工程实际。文中也阐述了作者由震害引发的思考和设计建议，并用中英文双语出版，相信对全世界建筑领域的工作者尤其是工程技术人员，有很好的参考价值。

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中国建筑工业出版社出版、发行（北京西郊百万庄）
各地新华书店、建筑书店经销
北京嘉泰利德公司制版
北京方嘉彩色印刷有限责任公司印刷
*
开本：880×1230毫米　1/16　印张：23　字数：718千字
2009年4月第一版　2009年4月第一次印刷
印数：1—2000册　定价：184.00元
ISBN 978-7-112-10809-1
（18059）

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序一

2008年5月12日在我国四川汶川发生里氏震级8级的强烈地震，震中位于四川阿坝州汶川县映秀镇（北纬31.0°，东经103.4°），震源深度13～14 km。受灾地区波及四川、甘肃、陕西、重庆、云南等10个省市的417个县（市、区），4667个乡镇、48810个村庄，受灾总面积接近50万km^2，其中极灾区和重灾区面积达13.2km^2；在这次地震中受灾人口多达4625.7万人，灾后无房可住的人口估计要达到一半以上，其中因灾害影响需要紧急转移的人口多达1510.6万人，截止2008年10月10日经确认因地震灾害遇难的人数为69227人，失踪人数17923人，两者相加超过8万人，因地震灾害受伤的人数达到37.46万人，地震造成的直接经济损失达8000亿元人民币。这次地震给中国人民造成了近代史上罕见的损失，举国震惊、环球关注。

地震是人类无法掌控的自然现象，但是地震造成的损失和由此酿成的灾害并非一定不可避免。要减轻或消除地震灾害首先要搞清造成地震灾害的根本原因。地震灾害的本质说到底是一种土木工程灾害。造成土木工程灾害的主要原因是：土木工程（大到一个城市，小到一个农舍）在从规划、建设到使用过程中由于应用不当的知识和技术，如：不当的选址，不当的抗震设防、设计、施工，以及不当的使用和维护导致所建造的包括房屋建筑在内的土木工程不能抵御突发的地震作用，以致造成土木工程的失效、破坏和倒塌，导致人民生命财产损失和社会经济发展停滞，也就是说酿成了灾害。这里提到的土木工程包括所有的建筑，地上和地下的、重大和一般的土木工程设施，例如：水库、铁路、公路、桥梁、隧道以及各种港口、矿山和工厂等。因此要减轻地震灾害，最重要、最有效的措施应该要首先确保土木工程在地震环境下的安全，也就是要依靠科学的工程抗震方法，其中包括确定适当的设防水平、合理的设防目标和科学的设防技术。具体来说就是要注意对工程进行正确的选址、设计、施工、使用、维护、加固和保养等。

科学的工程抗震技术主要来源于经验，经验主要来源于大地震中的工程震害教训和总结。这是由工程师们通过对工程震害的不断观察、分析、总结、再实践、再观察、再总结中获得的。从1906年美国旧金山地震开始，世界工程界经过百年来的努力，已经形成了一门专门研究和解决土木工程抗御地震破坏的学科——地震工程，并将百年来不断从工程震害资料中获得的经验和教训凝练成适于工程应用的抗震设计规范，成为人类能确保自己在地震环境下继续生存和持续发展的重要技术保障。因此工程在地震中的破坏现象和震害资料历来为地震工程界所重视。

中国建筑西南设计研究院有限公司在我国是一个有重要影响的从事民用建筑设计和研究的单位，因为地处我国西南地震活动区，长期来一直对建筑抗震十分重视，在建筑抗震设计方面积累了丰富经验和研究成果。汶川地震发生后，该院在第一时间组织了大量的专业技术人员奔赴灾区各地，进行建筑结构震害调查和评估，收集了大量的震害资料和其他相关的重要资料。为了使这些宝贵的资料能及时为国内外同行分享，他们在对这些震害现象进行认真分析和研究的同时，抓紧时间将收集到的资料整理、分类并计划立即出版，取名为：来自汶川大地震亲历者的第一手资料——结构工程师的视界与思考。这一举措不仅对这个地区的灾后重建有十分重要的指导作用，而且必将会对今后的抗震研究、改进工程抗震设计，提高我国抗震设计规范的水平产生积极的影响。

由中国建筑西南设计研究院有限公司整理出版的这本集子除了具有一般震害资料出版物所具有的特点以外，它还有以下几点特别值得关注：

第一，汶川地震是一次世界上十分罕见的，发生在内陆的震级达到 8 级且又在人口稠密地区的板内特大地震。对这样特大地震的工程震害资料，在世界上更是绝无仅有、极其珍贵的，它能反映工程建筑在板内特大地震作用下的破坏性状和特点。众所周知，尽管世界上的大陆面积远比海洋的面积小，但是人类的生存环境以及发展的空间绝大部分都是在陆地上。世界上许多地方都发生过 8 级或 8 级以上的大地震，但大多数都是发生在板块边缘的非陆地地震（如 1960 年的智利地震，1964 年的阿拉斯加地震，1985 年的墨西哥地震等）。尽管这些地震也曾造成大量陆地上的建筑破坏，但是发生在内陆的板内特大地震与发生在非陆地的板缘地震在性质上有什么不同，它们对工程的破坏作用又有什么差异，一直是土木工程界十分关注的问题。因此这本集子所收集的资料无疑会引起全世界工程界的极大关注。

第二，这本集子收集了在这次地震中，从破坏极其严重的地震烈度达到 XI 度的极震区到破坏较轻的轻灾区的工程震害资料；更难能可贵的是这些资料中覆盖了大量的按照我国地震区划图毋须进行抗震设防的建筑物和应按照 VI 度、VII(–) 度，VII 度和 VII(+) 度多种不同设防水平设计建造的建筑物，而在设防的建筑中又有根据不同版本的抗震设计规范进行设计的。汶川地震给我们提供了在不同地震烈度作用下，按照不同设防水准和不同抗震设计规范设计的建筑物在地震中表现出来的多种破坏形态的广谱震害资料；地震给人类带来了严重的灾害，但同时又是一个天然的实验室，给人类提供了如此丰富的依靠人类自己永远也无法获取的具有重要科学价值的海量资料。毋庸多说，这些资料是弥足珍贵的。

第三，这本集子的作者中国建筑西南设计研究院有限公司地处西南地震活动区，他们几十年来亲手在这个地区设计了大量的各类工程建筑。这些建筑物在这次地震中经历了各种不同程度的地震影响，造成了不同程度的破坏。他们不仅收集和掌握了震害资料，更难得的是他们还提供了大量的在地震中遭到不同程度破坏的建筑物的原始设计资料和建造资料。这就为分析各类建筑物产生不同程度的震害原因提供了十分难得的依据。他们按建筑结构型式分类收录了框架结构、框架 – 剪力墙结构、砌体结构、底框 – 抗震墙砖混结构、厂房、网架、高耸结构等各类建筑结构的破损情况，对楼梯、砌体填充墙等围护结构、防震缝、农村自建房等震害也进行了专章整理，除此之外， 还专辟章节收录了成都五个城区的建筑震害以及他们在重灾区设计的各类建筑在这次地震中遭遇的各种震害。

第四，作为一部专门介绍建筑震害的出版物来说，当然首先应该要尽量客观地、全面地、详尽地介绍震害的本身，让各方面的专家和后人进行分析和思考，以便仁者见仁，智者见智，各自从中得到应有的结论。毫无疑问，本集的作者们已经做到了这一点；但是他们也不受此局限，在客观、全面、详尽展示震害资料的同时，也介绍了他们对于震害的分析和从中引出的结论。这就充分发挥了作者们曾经设计这些建筑物，熟悉这些建筑物，从而就有可能对这些建筑物的震害原

因获得更接近实际的结论的优势。例如，他们曾在汶川、汉旺、都江堰、彭州、绵竹等重灾区设计了大量建筑物，所以在灾区考察时都是带着设计中的问题或疑惑进行考察和寻找答案的，在他们的著作中几乎处处都能见到这样的痕迹，例如，从第二章到第十三章，都是以“思考与建议”结尾。他们力图完成从感性认识到理性认识的飞跃，得出一些规律性的东西，并且提出了诸如实现“强柱弱梁”、“强剪弱弯”，提高极限承载能力、变形和耗能能力的途径或措施等等建议。不过这里也要提醒读者们在阅读这些章节内容时，一方面可以分享作者们的见解和观点，同时也要注意发挥独立思考精神，见仁见智，从中引出自己的结论。

除此以外，本书还有许多重要的特点，例如内容丰富，叙述生动具体、说理清晰细致，力求从多种视角展示各种震害。以楼梯（第九章）为例，他们通过 89 张照片展示了板式楼梯（又细分梯板、平台板、平台梁）、梁式楼梯、楼梯施工缝的震害；再如，作者们在介绍白鹿镇学校求知楼的震害时，对一至四层楼的 12 间教室，每层 3 间，共展示了 78 张照片，对每面墙的开裂状况，以及楼梯间、走廊墙面的破坏都作了细致的介绍。尽管目前的水平还不足以对震害作出完美的解释，但是这类不可再得的原始资料，将来也许还会授人以启示。值得一提的是，全集采用了汉英两种文字，一方面可以让全世界分享他们的资源，同时也表达了中国灾区的工程师们对世界各国在汶川大地震中对灾区援助和关注的一种答谢。

逝者如斯夫！汶川地震过去已近一年，但它带给我们民族的伤痛仍历历在目。正像温家宝总理所指明的那样：一个民族在一场大的灾难之后必定会有一个大的进步。这本著作的出版标志着我们的中国建筑西南设计研究院有限公司的同行们正在向着这个大的进步迈出自己有力的步伐！

谢礼立

中国工程院院士　谢礼立

2009 年 2 月 1 日

Foreword 1

On May 12, 2008, a tremendous earthquake with Magnitude 8.0 happened in Wenchuan county, Sichuan province. The earthquake's epicenter locates in Yingxiu town (31.0N, 103.4E) of Wenchuan County, 13-14m below ground. 10 provinces like Sichuan, Gansu, Shanxi, Chongqing, Yunnan, with totally 417 counties, 4667 towns and 48810 villages, are influence by the earthquake. The earthquake hit area reaches 500000 km^2, with heavy and catastrophic destroyed area 132000 km^2. 46.257 million people suffer in this earthquake, half of them lost their home and 15.106 million people are evacuated. Until October 10, 2008, official statistics shows 69227 persons lost, 17923 persons missing, 374600 persons hurt and total economic lost reaches 800 billion RMB. This earthquake causes astonishing lost in the contemporary history of China. The whole country moans and attentions from the whole world converge to China at this moment.

Earthquake is an uncontrollable natural phenomenon, but it doesn't mean the damage and lost caused by earthquake are uncontrollable. In order to eliminate the damage caused by earthquake, we firstly should make clear the mechanism of it. Earthquake disaster in nature is a kind of civil engineering disaster, which is caused by the following reason. A civil engineering structures, from a city to a small cottage, may use improper knowledge and technologies in designing, constructing and operating stage, such as bad site selection, unqualified earthquake resistance design and construction, mal-operating and maintaining and etc. All these factors will make the civil engineering projects, including buildings, vulnerable to sudden earthquakes and then result in failure of engineering structures, lost of human lives and impediment of economic development. Then an earthquake becomes an earthquake disaster. Here the civil engineering structures we mentioned include buildings, on-ground and underground structures, important and average civil engineering structures, such as dams, railways, motorways, bridges, tunnels, harbors, mines, factories and etc. In order to relief earthquake disasters, the most important and effective measure should be promising the safety of civil engineering structures in earthquakes, which means insisting scientific methods in earthquake resistance, including selecting correct earthquake fortification level, choosing proper earthquake fortification objectives and employing scientific fortification technologies. In practical saying, we should emphasize the correction on site selection, design, construction, operating, reparation, consolidation and maintenance of civil engineering structures.

The scientific earthquake resistance technologies mainly come from experiences, which are summarized from disastrous earthquakes. These technologies are obtained through a longtime procedure of observation, analysis, summarization, re-applying, re-observation and re-summarization of earthquakes. Since the 1906 San Francisco earthquake in United States, by a hundred years' hard work of international engineering industry, a scientific

discipline earthquake engineering, which studies and solves earthquake resistance problems of engineering structures, has been established. Based on experiences and lessons instantly got from earthquake disasters in last one hundred years, this discipline develops a set of practical earthquake resisting codes which is suitable for engineering usage, and also it becomes a technical protection for human beings surviving and developing under earthquake circumstances. Because of this, recording documents about civil engineering structures damaged in earthquakes are always expected by earthquake engineering industry.

China Southwest Architectural Design & Research Institute Co. Ltd. (CSWADI) is an important and reputational building design and research company in China. As located in southwest earthquake district of China, it always pays attentions to earthquakes and so accumulates abundant experiences in earthquake resistance design of buildings. After the happening of Wenchuan Earthquake, it organized professionals and experts getting into the earthquake area to investigate and assess seismic damage on buildings and collect relative information. In order to share the precious information with domestic and international colleagues, they conscientiously analyzed the information, sorted them out and planned to publish this book *Experience the Wenchuan Earthquake——structural engineers' point and view*. This act will not only direct the reconstruction of earthquake area but also influence passively the earthquake resistance research, strengthening earthquake resistance design and improve the standard of Chinese earthquake resistance code.

This book compilated by CSWADI shows several highlights rather than the common characteristics of other earthquake books:

First, Wenchuan Earthquake is a rarely happened catastrophic earthquake. It reaches magnitude 8.0 and happens in a high population district inside a geographic plate. Information about this kind of earthquake is precious and unique and can reflect the characteristics of this kind of earthquake damage to civil engineering structures. As we all know, although land area is much smaller than ocean area, human beings' main living spaces and developing places are on land. From global angle, many places encounter giant earthquakes with magnitude 8.0 or above, but most of them happen along the border of plates (like Chile earthquake in 1960, Alaska earthquake in 1964, Mexico earthquake in 1985 and etc.) These earthquakes also produce astonishing damages to buildings, but what is the difference between in-plate earthquake and those happened on the plate borders, what is the difference for the damage mechanisms of these two kinds of earthquakes? These questions continuously puzzled the engineering industry. So information and materials collected by this book will definitely attract attentions from international civil engineering industry.

Second, this book shows information collected from heavily damaged area with Earthquake

Intensity XI to light damaged area. More important, it covers lots of buildings which have not consider earthquake resistance and other correspondent buildings which belong to earthquake resistance class VI, VII(-), VII and VII(+) respectively. It also contains buildings located in the same earthquake resistance district but designed to the national codes of different times. The Wenchuan Earthquake provides us with abundant information of corruption patterns for buildings located in different intensity districts, designed to different earthquake resistance classes and different codes. Earthquake brings disasters to human beings, but meanwhile it works as a natural lab providing so much scientific information which can't be obtained by human beings themselves. In one word, this book is priceless.

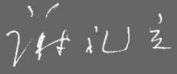
Third, the author of this book, Chinese Southwest Architectural Design & Research Institute (CSWADI) situated in the southwest earthquake district of China and designed lots of buildings there. All these buildings experienced influence in this earthquake, and some of them suffered damages. Engineers from CSWADI not only collected earthquake information but also provided the original design and construction information about the buildings damaged in this earthquake. These materials provided us with reference to analyze different earthquake damages on buildings. They sorted out earthquake damages according to buildings' structural types as frames, frame-shear wall structures, masonry buildings, masonry buildings with bottom-frame, factories, lattice shells, high-rise structures and etc. They also reserved chapters for sub-structures like stairs, masonry partitions, seismic joints and self-constructed houses in rural areas. Besides, they used specific chapters to present damaged buildings in Chengdu and damaged buildings they designed in the earthquake hit area.

Fourth, as a book to introduce building damages in earthquake, it should describe the damages objectively and comprehensively and inspire engineers and professionals to find out their own answers from the earthquake. Undoubtedly, authors of this book have reached these goals, but they are not restricted by these goals. When objectively and comprehensively analyzed the earthquake materials, they also drew their conclusions and considerations about this earthquake. This act used their understanding of the buildings which designed by them and might excavate the true facts hided behind the earthquake. For example, they investigated lots of buildings in earthquake area as Wenchuan, Hanwang, Dujiangyan and Pengzhou and observed these buildings with concerns and views from structural designers. We can find signs of their reflection everywhere in this book, since all chapters from chapter3 to chapter 12 are ended with *considerations and recommendations*. They tried to promote perceptual understanding to rational understanding, to summarize rules and principles, and they also proposed many measures to realize the principles "strong columns – weak beams" and "high shear capacity – low flexural capacity", to improve the ultimate bearing capacity, deformability

and energy exhausting ability buildings. But here I should remind the readers when reading these chapters, you can share the authors' ideas and opinions, but more important you need think independently and find out your own answers.

Besides, this book has many other important characteristics like abundant contents, detailed descriptions and clear explanations, and it also tries to interpret the earthquake from different angles. Take the stairs (Chapter 9) as an example, authors used 89 pictures showing the damage to slab stairs (further sorted as slabs, stair platforms and platform beams), beam stairs and damage to construction gaps. Another example was when authors introduced earthquake damages to the main building of Bailu Primary School, they showed 78 pictures, from 12 classrooms located from ground floor to fourth floor, to present details of cracks on every wall, corridor and stair. Although current technology can't explain perfectly the earthquake damage, this indispensible information about this earthquake can enlighten our descendants. Finally I should remind this book is written in two languages, English and Chinese. This provides the chance for the world to share these materials and meanwhile shows our appreciation for the helps and attentions we received from overseas.

Time flies away! Although it almost has been a year from Wenchuan Eartqhuake, the pain it brings to us is still clear. As pointed out by Chinese Prime Minister Wen Jiabao, "a catastrophic disaster can only make a nation progress another step". The publication of this book also symbolizes my peers from China Southwest Architectural Design & Research Institute Co. Ltd. stride ahead to this objective.

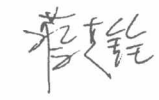


Professor Xie Lili
Member of Chinese Academy of Engineering
February 1, 2009

序二

当我于2008年5月12日获悉大陆四川发生规模7.8级[①]的大地震时，除了让我深感震惊外，也使我的思绪再度回到1999年台湾发生9·21集集地震之后的种种灾情；虽是发生于两个时空不同的地震，造成的却是相同的屋倒人亡、天人永离的悲惨情境。这说明了人类恐尚未在痛苦的历史经验中积累与发展出足够的能力，来免于此种悲剧的一再上演。

在台湾9·21集集地震后，我们作了相当多的灾情调查、统计与分析，以作为未来执行相关防灾与减灾工作的重要参考。很高兴地见到冯远教授与中国建筑西南设计研究院有限公司的专家在很有限的时间内共同编辑了《来自汶川大地震亲历者的第一手资料——结构工程师的视界与思考》一书，书中搜集了大量的建筑结构震害的照片，实足作为后续地震工程推展工作的最佳参考。也希望藉由该书的出版，传承更多的震灾经验与教训，进而促使地震工程能有更进一步的发展，有效减低地震对人类所带来的苦难。



台湾大学土木系教授　蔡克铨

2009年2月1日

① 后更正为8.0级。

Foreword 2

When I learned the devastating earthquake of magnitude 7.8 [1] occurred in Sichuan province on May 12, 2008, I was astonished by the severe human lives and property losses. The news brought my thoughts back to the grieving scenes of Taiwan Chi-Chi Earthquake occurred on September 21 in 1999. Although these two major earthquakes took place in different times and locations, they both caused tremendous amount of damages on built-environment and made human beings suffer huge losses. This reveals that we human beings have not gained enough abilities from historical experiences to prevent this kind of tragedy from happening again.

After the Taiwan Chi-Chi Earthquake, we have conducted earthquake damage investigations and analyses in order to gain insight into the key works for earthquake disaster mitigation. I am very pleased to see Professor Feng Yuan and her colleagues in China Southwest Architectural Design and Research Institute Crop. Ltd completed this book – *experience the Wenchuan Earthquake – from structural engineers point and view* – in such a short time. This book has collected many pictures about the damaged buildings in the earthquake severely damaged area. It is an ideal reference for the study of earthquake engineering. It is my wish, through the publishing of this book, more lessons can be learned and experiences can be shared. Thus, earthquake engineering can be advanced thereby reducing future earthquake disasters.

Professor Tsai, Keh-Chyuan
Department of Civil Engineering
National Taiwan University
February 1, 2009

[1] Corrected it to Ms 8.0 later.

巻頭言

2008年5月に起きた汶川大地震は死者9万人にも及ぶ大被害をもたらした。中国政府、国民諸団体の懸命の救援・復旧活動によりこの天災は克服されたが、この貴重な経験を後世に生かす為には、被災の事実を細大漏らさず記録し、分析と総合を通して被災実態を客観的に把握することが重要である。この度の西南設計院による被害調査報告の出版はこの意味で極めて貴重なものであり、歓迎すべき快挙である。

私が汶川大地震の被災現場に立つことができたのは、１９９３年に発足した日中建築構造技術交流会のお陰である。交流会は現在迄に8回に及び、ほぼ2年毎に開催されてきた。取り上げられたテーマは構造技術全般に及ぶが、その基調は耐震設計であつた。この間、兵庫県南部地震（1995)、集集大地震（1999)、汶川大地震（2008）が起こったことになる。2008年7月には急遽第7回日中建築構造技術交流会第三次成都会議（討論会）が成都において持たれ、都江堰の被害調査及び汶川大地震の被害についての意見交換が行われた。日本においても東京で２００８年９月に汶川大地震調査報告会が開かれ、中国における震災に対する強い関心が寄せられた。

汶川大地震における地震記録については未だ詳細な情報が公表されていない。しかし、被害の程度、範囲から見て、兵庫県南部地震や集集大地震のそれと遜色がないものと判断できる。

建物は基本的に重力に対して設計されている。重力の加速度は一定（980cm/s^2）であり、重力は単純に力として考えれば良い。地震の荷重効果は重力ほど単純ではない。地震動には水平動と上下動があるが、すでに建物は重力に対して設計されているので、上下動よりも水平動が重要である。水平動の加速度は時々刻々に変化し、これが建物に振動をもたらす。従って、地震動の荷重効果としては時々刻々の加速度に対応する地震力と、振動をもたらすエネルギー入力が重要となる。地震に対する建物の抵抗力としては、地震力に抵抗する為の地震抵抗力とエネルギー吸収能力（粘り強さ）が必要となる。一方建物は、重力に対して設計されるが、重力場においてポテンシャルエネルギーを持つことになる。建物が水平地震動によって水平方向に変位すると、建物の重心の高さは下がり、これによりポテンシャルエネルギーの一部は解放される。このように建物は地震によるエネルギーと、重力場におけるポテンシャルエネルギーの解放分（これをP-δ効果と呼ぶ）を受けることになり、これ等を吸収できなくなると、P-δ効果により完全に崩壊してしまう。P-δ効果は極めて重要であるにも拘らず、まだ、世界的に見て、満足な型で設計に考慮されていない。

更に重要な問題は、地震動のばらつきである。最近の地震学の発達によって、地震動予測技術は急速に進歩した。震源のパラメータの設定しだいでは、いくらでも強い地震動が予測される可能性がある。これに対処する為には、設計地震動のレベルを多段階に設定する必要が出てきた。従来は2段階の設定が主であつたが、更に3段階、4段階の設定も必要となつてくるであろう。

汶川大地震における被害の主因は地震による建物の崩壊で、建物は主として煉瓦造で一部鉄筋コンクリート構造が含まれていた。煉瓦造は構造素材として引張応力に対する抵抗力が低く、エネルギー吸収能力に乏しい。少なくとも、高層建築に要求されるエネルギー吸収能力に欠けている。低層に用いる場合でも開口の大きい建物には不向きである。日本では 1923 年の関東大震災の経験から純煉瓦造は禁止されている。ただし、この措置の妥当性について結論が得られている訳ではない。

いずれにしても、汶川大地震の建物の被害は極めて貴重な経験であり、地震入力と被害の相関関係を採る上で欠かせないものである。

この度の出版が耐震工学の発展に大きく貢献することを期待して止まない。

秋山宏

東京大学名誉教授　秋山宏

2009 年 1 月 21 日

序三

2008 年 5 月 12 日发生的汶川大地震夺去了近 9 万人的生命。中国政府和人民竭尽全力的抗震救灾活动克服了这场天灾。为让这次宝贵的经验造福于后世，详细地记录受灾实情，通过综合分析客观掌握受灾的实态是一件非常重要的工作。从这个意义上来说，中国建筑西南设计研究院有限公司主编的震灾调查报告集的出版是一件非常宝贵并值得欢迎的壮举。

我因成立于 1993 年的中日建筑结构技术交流会之缘到过汶川大地震的受灾现场。中日建筑结构技术交流会每两年一届迄今已召开八届。每届交流会都以建筑物的抗震设计为主题，同时概括建筑结构技术的所有分支。交流会成立到现在，发生了兵库县南部地震（阪神大地震，1995 年），集集大地震（1999 年），汶川大地震（2008 年）。2008 年 7 月在成都紧急召开了第 7 届中日建筑结构技术交流会第 3 次成都会议（研讨会），日中双方的建筑结构专家与设计技术人员考察了都江堰的受灾现场，并就受灾原因交换了意见。2008 年 9 月在日本东京也举办了汶川大地震调查报告会，日本各方对发生在中国的震灾表示了极大的关心。

尽管还没有正式公布有关汶川大地震地震记录的详细信息，但可以断言此次地震造成的灾害程度和波及范围绝不亚于兵库县南部地震和集集大地震。

建筑物一般以保证重力作用下的安全性进行结构设计。重力加速度（$9.8m/s^2$）不变，因此将重力按单纯的力考虑即可。但地震的荷载效应则不如重力般单纯，地震动包含水平震动和垂直震动。由于建筑物的初期设计已考虑对重力的安全性，考虑地震效应时水平震动效应比垂直震动效应更重要。水平震动的加速度时时刻刻不断变化，这种变化使建筑物也发生振动。因此，与时刻变化的加速度相对应的地震力，以及让建筑物发生振动的地震的输入能量成为衡量地震效应的重要指标。作为建筑物的抗震能力，水平抵抗力和能量吸收能力（延性）不可缺一。由于建筑物已针对重力作了设计，具备了势能，在水平地震动的影响下，建筑物的重心高度会下降，并释放出一部分势能。也就是说，地震时建筑物除承受地震的输入能量以外还将承受自身释放的一部分势能（称之为 $P-\delta$ 效应），如果不能吸收这些能量，$P-\delta$ 效应将导致建筑物的倒塌。尽管 $P-\delta$ 效应是一个非常重要的因素，然而世界上还没有让人满意的方式在设计中考虑它的影响。

比 $P-\delta$ 效应更重要的是地震动自身的偏差问题。伴随地震学的最新发展，地震动预测技术也有了急速的进步。如果对震源地诸参数作适当假定，不管多大的地震都有可能被预测。为此，设计用地震动的级别分类有必要在现行的 2 级分类之上追加第 3 级，第 4 级分类。

汶川大地震中的受害主要归结于建筑物的倒塌，倒塌的建筑物以砖混结构为主，也包括一部分钢筋混凝土结构。砖混结构里使用的材料只有很低的抗拉强度，缺乏能量吸收力，至少欠缺高层建筑所需的能量吸收能力。用在低层建筑时，对要求大开口的建筑物（教室等）也不太适合。日本吸收 1923 年关东大地震的经验教训在全国禁止砖混结构的使用。但这种做法是否妥当还没有得到最终的结论。

总而言之，汶川大地震中建筑物受到的灾害是一个非常宝贵的经验，受灾资料对搞清地震输入与受害程度的相互关系是必不可少的。

我衷心期待本资料集的出版能为工程抗震学的发展做出重大贡献。

秋山宏

东京大学名誉教授　秋山宏

2009 年 1 月 21 日

Foreword 3

The Wenchuan Earthquake happened in May 12, 2008, and took 90,000 lives away. The Chinese people and their government tried their best to rescue persons suffered in this disaster. In order to accumulate the experience for the goodness of our descendants, recording all the facts and details of Wenchuan Earthquake to enhance our understanding of this earthquake is a very important thing. In this meaning, the publishing of this documentary book, compiled by Chinese Southwest Architectural Design & Research Institute (CSWADI), will be an invaluable and memorial event.

I visited the earthquake-hit district with the assistance of the China-Japan Structural Communication Committee founded in 1993. This committee organized formal conferences every two years and totally eight conferences were held until now. Every time, earthquake resistance design remained a main topic in the conferences, as well as topics on all other branches in structural technology. From the beginning of the committee, we already experienced the South Hyogo-ken Earthquake (Kobe Earthquake, 1995), the Jiji Earthquake (1999) and the Wenchuan Earthquake (2008). In July, 2008, the third session of the 7th conference of the committee was urgently held in Chengdu, China. Experts and engineers from China and Japan visited the earthquake hit district in Dujiangyan City and exchanged their opinions about this disaster. In September, 2008, a reporting conference was also held in Tokyo and attendees showed great intentions for the earthquake happened in their neighbor - China.

Although the details of the Wenchuan Earthquake haven't been officially unveiled, the estimated damages and the affected area will be no smaller than those of the Kobe Earthquake and the Jiji Earthquake.

Building design generally considers structure's safety under vertical gravity. Because the gravity acceleration is a constant, we can take it as a simple vertical force exerting on buildings. But earthquake effect is more complicated than gravity; it contains horizontal and vertical vibrations. In the initial design of buildings, we already consider the gravity. When considering earthquake effect, horizontal vibrations are more important than vertical vibrations. The accelerations of horizontal vibrations are changing time by time and thus cause the vibrations of buildings. So the earthquake forces coordinating with the changing accelerations and the earthquake energy causing vibrations of buildings become two key parameters to evaluate earthquake effects. For the earthquake resisting buildings, the ability to resist horizontal forces and the ability to absorb energy (ductility) are both indispensable. A building is already designed to gravity and owns potential energy, so under the horizontal vibrations, its gravity center will descend and release part of the potential energy. In another word, in earthquakes, buildings will bear additional potential energy released by themselves (called P-δ effect), as well as the earthquake energy. If the additional energy can not be absorbed, the P-δ effect will collapse