出國報告（出國類別：研究）

美國加州大學聖地牙哥及柏克萊分校短期研究

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派赴國家：美國
出國期間：99 年 8 月 3 日~99 年 8 月 11 日
報告日期：99 年 11 月 11 日

摘要

出國報告名稱：美國加州大學聖地牙哥及柏克萊分校短期研究報告書

頁數 69 含附件：■ 是 □ 否

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/單位：工程技術組

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赴國外類別：□1.考察□2.進修■3.研究□4.實習□5.其他

關鍵詞：建築物耐震研究，地震工程，結構工程，結構實驗

內容摘要：

一.研究對象: 本次赴美國短期研究規劃行程由 99 年 8 月 3 日至 8 月 11 日合計 9 天，研究地點包括：(一)美國加州大學聖地牙哥分校，(二)太平洋地震工程研究中心(Pacific Earthquake Engineering Research Center, PEER)，(三)加州大學柏克萊分校，以蒐集美國有關建築物耐震法規及設計研究最新資料，並介紹我國在此領域之發展概況，藉此國際經驗交流，促進美國相關學者對我國之充分瞭解。

二.研究性質：包含參訪相關實驗設備、太平洋地震工程研究中心、研究及實驗室營運經驗交流、討論國際合作研究計畫可能性等相關內容。

三.研究內容：包含(一)赴美國加州大學聖地牙哥及柏克萊分校進行大型力學試驗課題短期研究，並順道參訪太平洋地震工程研究中心(PEER)，與美國建築物耐震研究專家交流技術、研究心得。(二)介紹本所近年來建築物耐震研究辦理情形及未來展望。(三)透過參訪以及討論方式彼此交換意見，以獲取相關成功經驗並取得合作聯繫管道。

四.心得建議：(一)美國加州大學聖地牙哥分校之結構工程系，因擁有完整之實驗設施群，近年來在大學排名已逐步攀升，也因爲大型力學實驗設備完善，除研究計畫案量維持穩定外，在結構耐震領域亦有舉足輕重之地位，本次參訪與研習行程，得以一窺該系之主要大型力學實驗設施，對未來材料實驗中心在實驗研究之發展，將有實質上之助益。(二)Powell 實驗設施群皆設有專職之技術師，針對實驗研究案件，研究人員僅規劃實驗計畫，設備

架設及實驗操作則由技術師負責，由此，可培育精良之技術人力。本所材料實驗中心在實驗操作方面仍仰賴臨時人力，實驗技術難以紮根，此爲日後需調整改善之處。(三)在實驗室營運維護方面，由於美國加州政府財政困窘，補助州立大學之經費減少，學校實驗室亦須自籌經費才得以運作，因此在人力增補與儀器設備維護方面，亦須撙節開支。本所材料實驗中心主要儀器設備之保固期限陸續到期，未來設備維護費用將逐步提高，除持續爭取科技計畫支援外，檢測業務的擴增亦是需要努力的方向。(四)本所 3000 噸萬能試驗機之設備容量，目前在世界上仍爲數一數二、絕無僅有之實驗設備，在與汪教授之言談間，似乎亦有國際合作研究之空間，因此，除了持續強化實驗室人員在大型力學實驗方面之技術能力外，亦需積極籌畫未來實驗研究之發展目標。(五)美國加州大學柏克萊分校及太平洋地震工程研究中心(PEER)爲國際知名之地震工程研究重鎮，實驗設備與研究課題與本所相近，其相關研究經驗非常值得本所借鏡，應持續實驗研究與營運經驗等方面的交流，以提升本所實驗能力。(六)本所應藉由國際合作研究的機會，汲取美國知名學者的研究經驗，以拓展本所國際知名度及提昇國際地位。(七)加州大學聖地牙哥分校結構工程系近年來之重點工作，主要以發展大型結構試驗爲主，包含大型橋梁模型之靜態及動態試驗、阻尼器、隔震器及束制斜撐之試驗，可做爲本所未來規劃相關研究方向及課題之參考。(八)柏克萊分校及太平洋地震工程研究中心(PEER)之研究方向，主要集中於 4 大研究領域包

含建築結構系統，橋梁和運輸系統，維生管線系統和資訊技術，

其研究內容可做為本所未來規劃相關研究課題之參考。

目錄

壹、緣起與目的

一、計畫緣起

美國加州大學聖地牙哥及柏克萊分校爲國際知名之地震工程研究重鎮，實驗設備與研究課題與本所相近，其相關研究經驗非常值得本所借鏡。經考量本所材料實驗中心營運初始，亟需吸收國外實驗研究與營運經驗，以提升實驗能力，爰於本(99)年度編列赴該校短期研究計畫。

本次赴美國加州大學聖地牙哥及柏克萊分校進行大型力學試驗課題短期研究，並順道參訪太平洋地震工程研究中心(PEER)，除蒐集美國有關建築物耐震法規及設計研究最新資料，並分享我國(本所)在建築結構耐震研究領域之成果與經驗，爭取國際合作機會外，同時進行實驗室營運經驗交流，以提昇本所材料實驗中心營運效能。

二、計畫目的

(1)蒐集美國有關建築物耐震法規及設計研究最新資料，並介紹我國在此領域之發展概況，藉此國際經驗交流，促進美國相關學者對我國之充分瞭解。

(2)藉由分享我國(本所)在建築結構耐震研究領域之成果及經驗，獲得美國相關學者之肯定，並爭取國際合作機會。

(3)藉赴加州大學聖地牙哥及柏克萊分校短期研究，及參訪太平洋地震工程研究中心之便，進行實驗室營運經驗的交流，以提昇本所材料實驗中心的營運效能。

貳、參訪過程

本次美國短期研究規劃行程由 99 年 8 月 3 日至 8 月 11 日合計 9 天，參訪行程詳如下表：

表 1 美國短期研究行程表

日　　期	活　　動　　內　　容	備　　註
8 月 3 日(二)	往程	台北→洛杉磯→聖地牙哥
8 月 4 日(三)	參訪加州大學聖地牙哥分校結構工程系相關實驗設備(含室外震動台、隔震墊及相關實驗設備)。	聖地牙哥
8 月 5 日(四)	研究及實驗室營運經驗交流(教授、研究人員及研究生)。	聖地牙哥
8 月 6 日(五)	討論國際合作研究計畫可能性(教授、研究人員及研究生)。	聖地牙哥
8 月 7 日(六)	聖地牙哥至舊金山。	聖地牙哥→舊金山
8 月 8 日(日)	舊金山著名土木建築物參觀(含金門大橋)	舊金山
8 月 9 日(一)	(1) 參訪加州大學柏克萊分校土木及環工系相關實驗設備(含震動台及相關實驗設備)。 (2) 研究及實驗室營運經驗交流(教授、研究人員及研究生)。	舊金山
8 月 10 日(二)	參訪太平洋地震工程研究中心(PEER)相關實驗設備。	舊金山
8 月 11 日(三)	返程	舊金山→台北

一、美國加州大學聖地牙哥分校

美國加州大學聖地牙哥分校(University of California, San Diego, UCSD)(圖 1)位於南加州聖地牙哥市的拉荷亞(La Jolla)社區，成立於 1960 年，雖然建校只有短短的五十年，但是已經成爲美國頂尖以研究科學爲主的公立大學。該校被譽爲“公立常春藤”之一，同時也是美國重要的學術聯盟美國大學聯合會(Association of American Universities)的成員。本次參訪、研習之系所爲該校之結構工程系，主要在訪察該系之力學實驗設施，學習大型結構實驗方法，同時瞭解相關實驗研究計畫，以及實驗室之營運與維護，由 Professor Chia-Ming, Uang(汪)接待與解說。

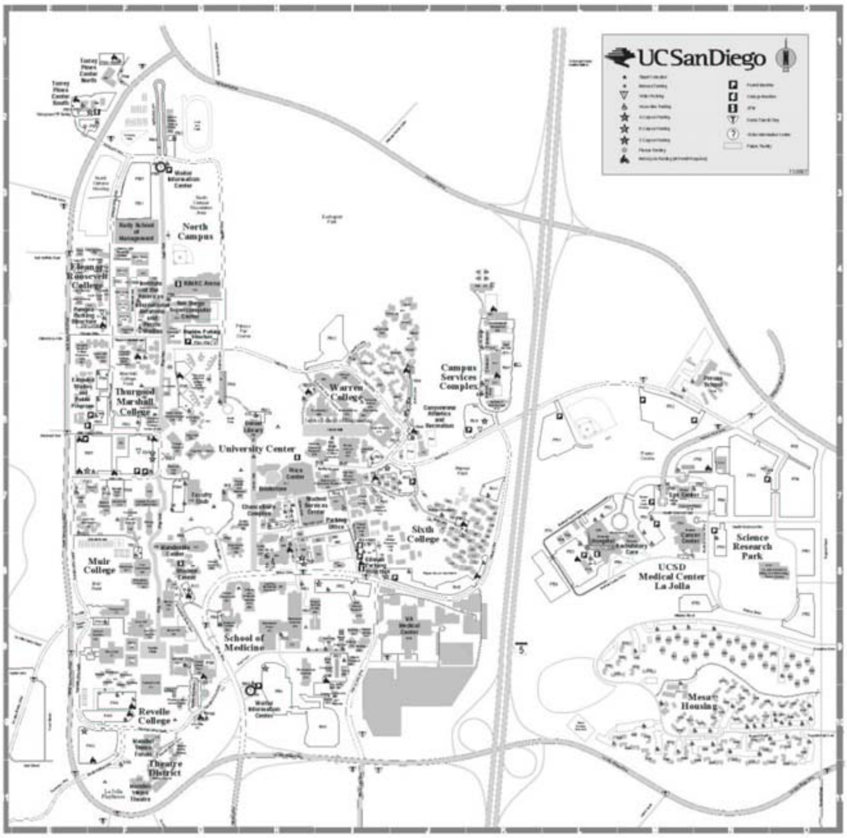


圖 1 美國加州大學聖地牙哥分校校園地圖

二、UCSD 結構工程系簡介

UCSD 結構工程系於 1999 年由應用力學與工程科學(Applied Mechanics and Engineering Sciences, AMES)系之結構工組獨立出來，早期 AMES 專注於傳統工程學位課程，結構工程系獨自成立後，將該系的目標與願景，著重於結構力學與材料之學程規劃及研究發展，而無需像傳統土木工程系一般，需包括交通、測量、施工、廢水處理等課程內容，爲目前全美唯一的結構工程專門學程，也因此使該系在學術與研究方面居於世界之領導地位。

這十幾年來，結構工程系的研究發展重心多集中在 Charles Lee Powell Structural Research Laboratories(圖 2)，它落成於 1986 年，是全美第一個可提供全尺寸試驗之實驗室，可執行 5 層樓高建築或 35 公尺長橋樑之結構試驗。而在經歷 1989 年 Loma Prieta 地震及 1994 年 Northridge 地震之後，大尺寸或全尺寸結構試驗之需求快速增加，該系於 1993~94 年間完成 Structural Components and the Advanced Composite Structures Laboratories 之建置計畫，持續擴大各項實驗設施建置，其中包括 Caltrans 提供之 Structural Response Modification Devise (SRMD)。目前 Powell Structural Research Laboratories 已擁有全世界最大規模之實驗設施群，而在地震工程及複合結構領域之研究方面，也成爲國際公認頂尖的研究機構。

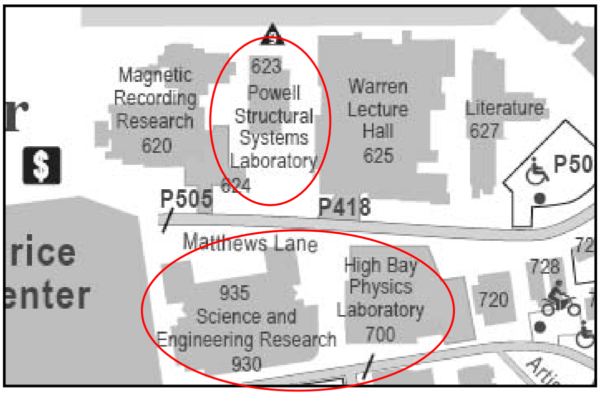


圖 2 結構工程系實驗設施群位置圖

在通往結構工程系實驗設施群的校園道路兩旁，佇立著許多大尺寸結構試驗後的試體殘骸(照片 1)，汪教授之博士後研究員亦一一解說各試體之試驗目的。這樣的擺飾，似乎也在教育來往行人，結構構件與材料在經歷強大負載後之破壞型態。

(a)碳纖維包覆 RC 柱試體殘骸

(b)RC 長柱試體殘骸

照片 1 置於校園道路兩旁之試體殘骸

三、Powell 結構工程實驗設施介紹

Powell 結構工程實驗設施群共有 12 項實驗室(設施)，各實驗室(設施)名稱如下所示，本次參訪與研習行程主要爲編號 1~4 項之實驗室。

- 結構系統實驗室(Structural Systems Laboratory)
- 結構構件實驗室(Structural Components Laboratory)
- Caltrans SRMD 振動台設施(Caltrans Seismic Response Modification Device)
- Englekirk 結構工程中心(Englekirk Structural Engineering Center)
- 土壤力學實驗室(Geomechanics Laboratory)

- 結構動力實驗室(Structural Dynamics Laboratory)
- 複合結構實驗室(Composite Structures Laboratory)
- 車輛現地實驗場(Mobile Field Laboratory)
- 創新複合材料實驗室(Advanced Composites Laboratory)
- 複合材料與航空結構實驗室(Composite and Aerospace Structures Laboratory)
- 複合材料製造實驗室(Composites Manufacturing and Characterization Laboratories)
- 非破壞檢測及結構健康監測實驗室(Non-Destructive Evaluation(NDE)/Structural Health Monitoring (SHM) Laboratories)

(一)結構系統實驗室

本實驗室成立於 1986 年，擁有 15 公尺高之反力牆及 37 公尺長之強力地板，使其成爲 1989 年 Loma Prieta 地震後，美國境內第一個可執行長跨度結構試驗之實驗室，目前該實驗室正致力於既有橋樑之修復補強技術開發與實驗研究，以及相關之檢測工作。本實驗室之實驗設施與容量說明如下：

1. 強力地板
   - 四孔鋼筋混凝土箱型梁
   - 長 37 m (120 ft)、寬 15 m (50 ft)
   - 樓板厚度爲 0.91 m (3 ft)
   - 預力錨錠孔間距爲 0.61 m×0.61 m (2 ft×2 ft)
   - 預力錨錠孔之負載爲 1,334 kN (300 kips)
   - 彎矩強度爲 108,600 kN-m (80,000 ft-kips)

2. 反力牆
   - 二孔後拉預力鋼筋混凝土箱型梁
   - 高 15 m (50 ft)、寬 9 m (30 ft)
   - 預力錨錠孔間距爲 0.61 m×0.61 m (2 ft×2 ft)

- 預力錨錠孔之負載爲 1,334 kN (300 kips)
- 剪力強度爲 11,876 kN (2,670 kips)
- 彎矩強度爲 108,600 kN-m (80,000 ft-kips)
- 可移動式反力牆
- 高 14.3 m (47 ft)、寬 4 m (13 ft)

3. 天車
   - 吊重 89 kN (20 kips)

結構系統實驗室外觀如照片 2 所示，參訪當天，實驗室人員正在拆卸已試驗完畢之橋樑試體(照片 3)。汪教授帶領我們進入實驗室，摘要說明該項試驗之目的與試驗方法，該試驗爲 Caltrans 所委託之橋樑系統單軸反力牆試驗，由照片 4 可看出橋柱之破壞情形，照片 5 則爲橋柱基座之錨固方式。汪教授亦順便說明該實驗室之設施，其中比較特別的是移動式反力牆(照片 6)，該反力牆高 14.3 公尺、寬 4 公尺，可在強力地板長向方向移動，配合固定式反力牆，可進行雙軸之反力牆試驗。由於實驗室人員正在拆除橋樑試體，爲安全起見，我們一行人並未深入實驗區域，同時爲避免妨礙拆除作業，在解說完畢後即離開該實驗室。

照片 2 結構系統實驗室外觀

照片 3 實驗室人員正在拆卸已試驗完畢之橋樑試體

照片 4 橋柱破壞試體

照片 5 橋柱錨定情形

照片 6 移動式反力牆

(二)結構構件實驗室

1989 年 Loma Prieta 地震後，由於大型結構構件試驗之需求與日俱增，擴增實驗室之測試空間已刻不容緩，因而結構構件實驗室於 1994 年落成。在落成啓用的那一年，美國發生 Northridge 大地震，造成鋼結構建築物的大規模損壞，因此 Powell 結構實驗設施群再度引領既有鋼結構構造物之修復補強，以及新建鋼結構構造物之施作方式等之檢測工作。本實驗室之實驗設施與容量說明如下：

1. 強力地板
   - 六孔鋼筋混凝土箱型梁
   - 反力牆前之可用空間為長 11.3 m (37 ft)、寬 15 m (50 ft)

- 總深度約 4.25 m (14 ft)，頂板厚 0.91 m (3 ft)

2. 反力牆
   - 高 9 m (30 ft)、寬 19 m (62.3 ft)
   - 牆厚 1.1 m (3.5 ft)

3. 振動台
   - 單軸，長 4.9 m (16 ft)，寬 3 m (10 ft)

結構構件實驗室外觀如照片 7 所示，汪教授的博士後研究員首先帶領我們進入該實驗室，在反力牆及強力地板上正架設著一組結構構件(照片 8 及 9)，欲進行撓曲試驗，並摘要說明該項試驗之目的與試驗方法。據博士所言，該構件係風力發電機立柱之縮小模型，該試驗乃爲瞭解風力發電機立柱受強風或地震力作用下之破壞模式，試體橫放則是爲了方便觀察試體於受力過程中所發生之變化。而針對構件之撓曲試驗方法，我們也分享了在台灣的試驗經驗。

在實驗室反力牆的一端，佇立著一座鋼構架(照片 10)，該鋼構架配合反力牆，得以執行三軸向加載試驗。反力牆另一端的前方則有一座小型單軸向振動台(照片 11)，由於其他實驗室已完成大型振動台之建置，此小型振動台已鮮少再使用。環顧四周之控制儀器與設備，亦多爲 MTS 公司之產品，爲此我們也與實驗室之技術師進行較深入之交談，針對設備之使用與操控性等進行經驗交流。

實驗室外面空地則堆置著一些試體殘骸，以及一些接合鐵件與構架，汪教授亦特別介紹其中一座反力鋼架(照片 12)，該反力鋼架配合反力牆，得以進行較複雜之加載試驗。

照片 7 結構構件實驗室外觀

照片 8 結構構件撓曲試驗

(a) 施力端

(b) 固定端

照片 9 結構構件端部配置

(a) 輔助構架配置

(b) 三軸試驗

照片 10 試驗輔助構架

照片 11 小型單軸向振動台

照片 12 反力鋼架

（三）Caltrans SRMD 振動台設施

南加州位於地震帶上，由於大地震來襲時，往往造成構造物之嚴重毀損，因此，近年來有關地震反應調節裝置(Seismic Response Modification Device, SRMD)，例如阻尼器、隔震器等，已逐漸應用於既有構造物之耐震修復補強工作。然而，這些不同尺寸與容量之耐震裝置的性能、壽命與耐磨耗能力便成爲需要探討與瞭解的課題。爲此，加州交通運輸部(California Department of Transportation, Caltrans)、加州大學聖地牙哥分校結構工程系、以及 MTS 公司等合作建置 SRMD 振動台(圖 3)，並於 1999 年開始運作。此振動台具有 6 個自由度，可執行阻尼器、隔震器等之全尺寸動態測試。

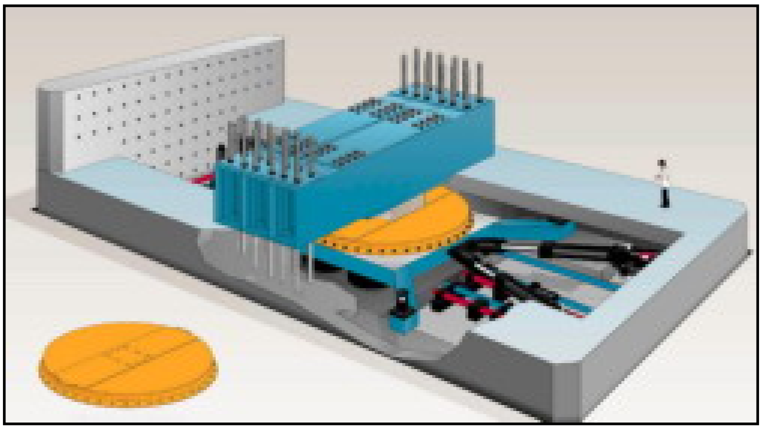


圖 3　Caltrans SRMD 振動台

此振動台系統係由預力混凝土反力構架、可移動式台座、以及 4 組水平放置之致動器所組成，台座可在 4 組靜油壓式、低摩擦阻力之支承上滑動，並有 4 支外伸之鋼臂支持，以提升系統之穩定性。此外，此振動台系統附加 2 組反力系統，其一爲上方之可移動式橫梁，可藉此施加垂直力，另外一組爲端部之反力牆，可用以測試阻尼器。振動台系統之設施與容量說明如下：

- 振動台尺寸：長 4.75 m、寬 3.685 m
- 垂直力：53,400 Kn (12,000 kips)
- 縱向力：8,900 kN (2,000 kips)
- 側向力：4,450 kN (1,000 kips)
- 垂直向位移：±0.127 m (±5 in)
- 縱向位移：±1.219 m (±48 in)
- 橫向位移：±0.610 m (±24 in)
- 垂直向速度：±254 mm/s (±10 in/s)
- 縱向速度：±1,800 mm/s (±70 in/s)
- 橫向速度：±760 mm/s (±30 in/s)
- 振動台轉角：±2 度
- 試體最大高度：1.524 m (60 in)

SRMD 振動台設置於 High Bay Physics Laboratory 建築物內(照片 13)。參訪當天，汪教授帶領我們進入該實驗室，實驗室佈告欄張貼著 SRMD 振動台的簡介(照片 14)，汪教授及實驗室技術人員爲我們簡要說明振動台之性能與應用。由於當天實驗室並沒有實驗進行，我們隨著汪教授進入振動台實驗區(照片 15)，照片 16 爲振動台兩端之斜向油壓致動器。汪教授實際說明振動台試驗方法，包括一般振動台試驗、隔震器之垂直力加載方式、阻尼器之架設與試驗方式等。於振動台旁尚有一部較老舊之實驗設備(照片 17)，據汪教授所言，該設備早期係用來做隔震器試驗，現已鮮少使用。

照片 13　High Bay Physics Laboratory 建築物外觀

照片 14　SRMD 振動台的簡介

照片 15　SRMD 振動台

照片 16　SRMD 振動台兩端之斜向油壓致動器

照片 17　隔震器試驗設備

（四）Englekirk 結構工程中心

Englekirk 結構工程中心位於 UCSD 校本部東方約 8 英哩之 Elliott 校區(圖 4)，是一座大型戶外實驗場，於 2005 年成為 Powell 結構工程實驗設施群的一員，2008 年獲得 International Accreditation Service, Inc.認可之測試實驗室。該實驗場之主要實驗設施包括 UCSD-NEES 戶外大型振動台、大型土壤與結構互制試驗場、以及爆破模擬試驗設施等。戶外大型振動台及大型土壤與結構互制試驗場可提供全尺寸結構系統之動態地震實驗研究；爆破模擬試驗設施可模擬炸彈爆炸對結構物之影響，從而探討強化結構系統之方法。

圖 4　Englekirk 結構工程中心位置圖

1　UCSD-NEES 戶外大型振動台

UCSD-NEES 戶外大型振動台長 40 ft、寬 25 ft，為世界第一座戶外振動台，同時也是全美規模最大之振動台(圖 5)，可執行重達 2,200 噸、最高 100 英尺之結構動態耐震試驗，利用強而有力之由壓致動器，其振動速度可達 6 ft/s，幾乎可模擬所有之地震紀錄。

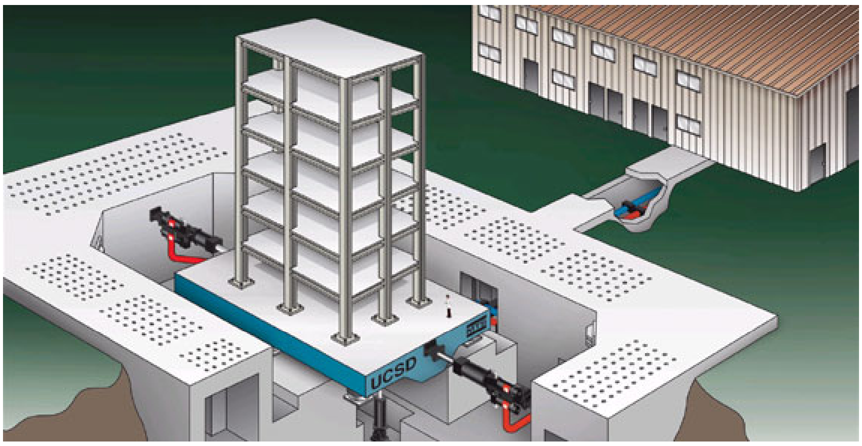


圖 5　UCSD-NEES 戶外大型振動台示意圖

2　大型土壤與結構互制試驗場

本試驗場由 Caltrans 資助興建，包括兩個可回塡之土坑、土壤及兩座反力牆，可執行土壤與結構互制之試驗研究，例如樁基礎、橋台擋土牆等。研究人員可於土坑填入不同土壤，模擬不同之的地質條件，並可探討由地震等造成之土壤液化或地層滑動現象。

3　爆破模擬試驗設施

本爆破模擬試驗設施(圖 6)可針對全尺寸柱、牆及其他結構構件進行可重複性、可控制性之爆破力模擬試驗。模擬設施係利用油壓致動器模擬爆炸震波所產生之衝擊力及速度，其作用在試體之衝擊速度於 1-2 ms 內即可達 50 mph，可模擬 50 磅 TNT 於結構物幾英尺內之爆炸行爲，至 5,000 磅 TNT 於 100 英尺外之爆炸行爲。

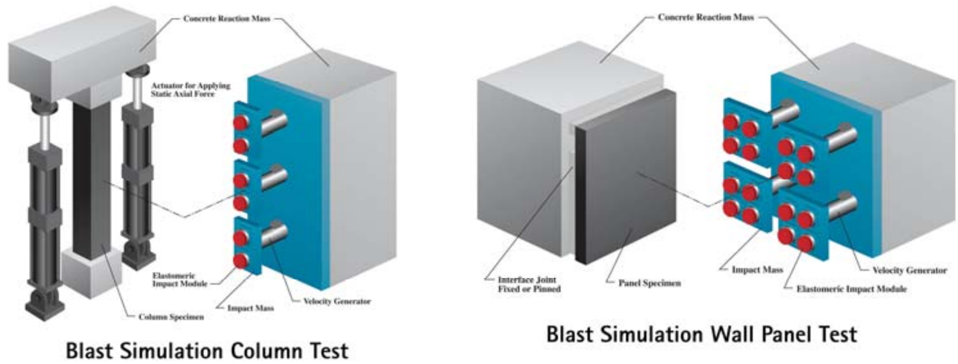


圖 5　爆破模擬試驗設施示意圖

由於 Englekirk 結構工程中心距 UCSD 校本部有一段距離，參訪當天，汪教授開車帶領我們至該實驗中心。該實驗廠區之腹地相當廣闊，戶外堆置著許許多多試驗完後之試體殘骸（照片 18），汪教授爲我們介紹幾個主要之試驗項目，例如風力發電機之振動台試驗、鋼構廠房之振動台試驗等(照片 19)。

再深入實驗廠區，便可見到大型土壤與結構互制試驗場(照片 20)，當天並沒有進行相關試驗。照片中，反力牆前方為土坑，依地質條件可填入適當之砂土，現場置有兩支試驗完之橋柱試體。照片後方即為戶外振動台，振動台兩端之紅色鋼架為試驗用反力架，振動台上正在進行混凝土細長柱試體之灌漿作業(照片21)，據現場技術人員說明，該柱將模擬橋柱進行動態耐震試驗。

汪教授帶我們進入 Englekirk 結構工程中心辦公室(照片 22)，在登錄參訪登記後，便進入戶外振動台設備室內(照片 23)。據汪教授之解說，目前該振動台僅可進行單軸向試驗(縱向)，惟仍留有日後擴充為雙軸向之設計(每端各兩支斜向致動器)。

參訪當天，於 Englekirk 結構工程中心辦公室的一端，正在進行複合材料板材之爆破模擬試驗(照片 24)，該試驗利用致動器快速作動產生高速之衝擊力撞擊板材，再以高速攝影機捕捉整個撞擊、破壞之過程，藉此探討板材承受爆破力之性能。據汪教授說明，以往以炸藥進行結構構件之爆破試驗，試驗過程雖然逼真，但當炸藥爆炸時，除所有測計瞬間毀壞外，更是揚起一片煙層，什麼也拍不到，無法獲取可用之試驗結果，因此，近來已改為使用模擬方式進行試驗，除方便紀錄試驗過程外，亦易於控制試驗之進行。

Englekirk 結構工程中心為本次 UCSD 參訪行程之最後一站，在這幾天來的行程中，除參觀各實驗室外，亦針對實驗研究計畫、大型力學實驗方法、實驗室營運管理等事項，就教於汪教授，收穫相當豐碩，也感謝汪教授及其博士後研究員之熱情接待。

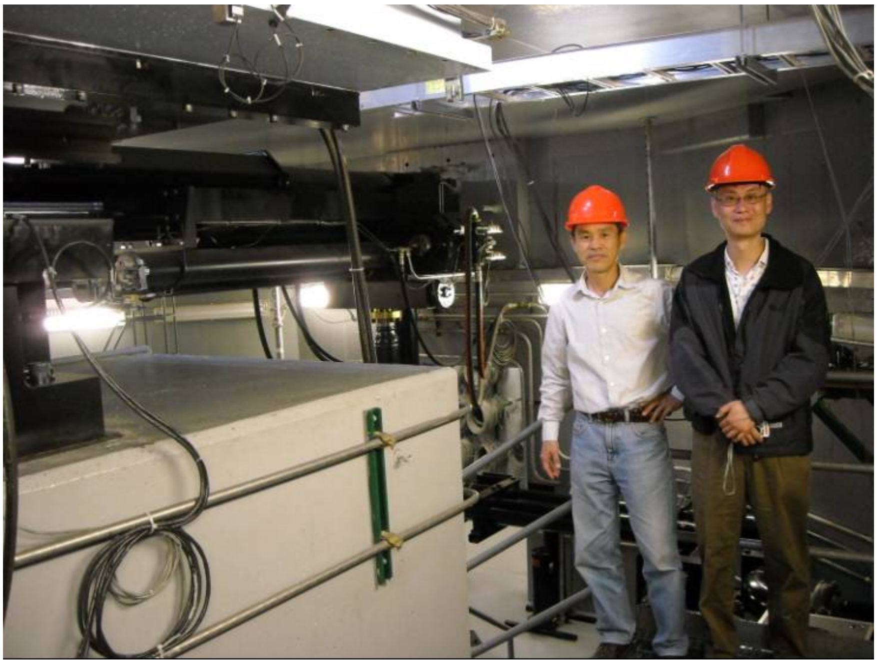
照片 18　試體堆置場

照片 19　風力發電機立柱（人後面）及鋼構架（地面）殘體

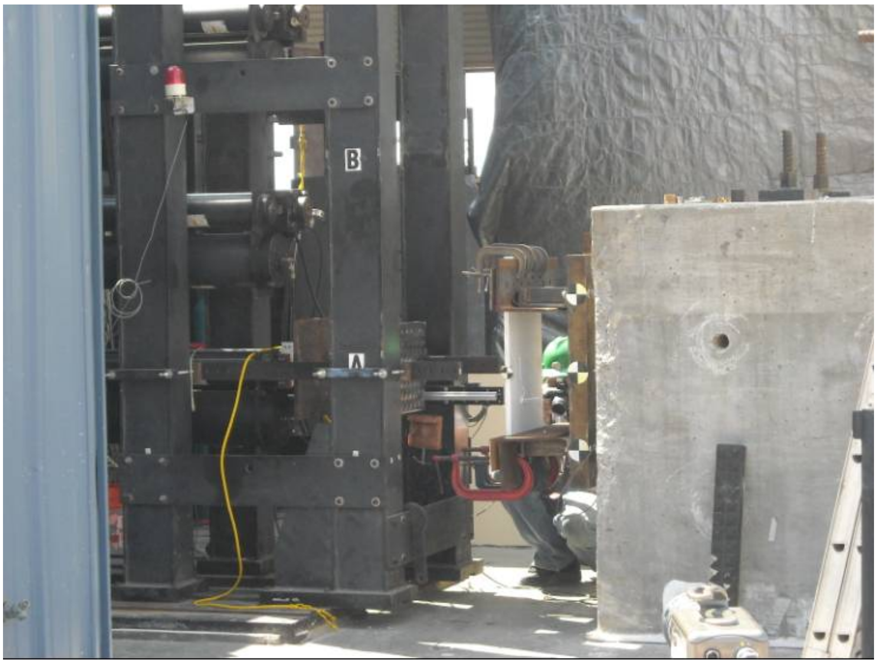
照片 20　大型土壤與結構互制試驗場

照片 21　混凝土細長柱試體之灌漿作業

照片 22　Englekirk 結構工程中心辦公室



照片 23　振動台設備室（右上方為致動器）



照片 24　複合材料板之爆破模擬試驗

四、柏克萊分校及太平洋地震工程研究中心(PEER)

(一)加州大學柏克萊分校

加州大學柏克萊分校(University of California, Berkeley)，爲美國最負盛名的一所公立研究型大學，位於舊金山東灣柏克萊市的山丘上，也是美國大學協會(Association of American Universities)的創始會員之一。學校每學期爲大學部和研究生提供將近 300 門選修課程。學校總面積爲約 27 平方公里，中心校園面積約爲 0.8 平方公里。

20 世紀中期是加州大學柏克萊分校在物理學、化學和生物學的黃金時代。藉由物理學家恩尼斯特·勞倫斯(Ernest O. Lawrence)發明的迴旋加速器，在這間學校的研究學者發現了許多重於鈾的元素。鉳(Berkelium)和鉲(Californium)即以這所大學的名字來命名的，而鐒(Lawrencium)和(Seaborgium)則是以此校的勞倫斯

和葛蘭·希柏格(Glenn T. Seaborg)的名字來命名的。

二次大戰時期，加州大學柏克萊分校的勞倫斯放射實驗室(Lawrence's Radiation Laboratory)承包美國軍方的原子彈研發計劃。1942 年，羅伯特·奧本海默(Robert Oppenheimer)教授被任命領導曼哈頓計劃的科學部門。

加州大學柏克萊分校在越南戰爭期間由於其學生對於美國政府的抗議而變得全球知名。1964 年在加州大學柏克萊分校發起的言論自由運動(Free Speech Movement)改變了一世代人對政治和道德的看法。

加州大學柏克萊分校圖書館共有 3 座主圖書館、24 座分科圖書館及 11 座附屬圖書館，藏書超過 1,000 萬冊，是北美地區第四大的圖書館，排名僅次於美國國會圖書館、哈佛大學圖書館，和耶魯大學圖書館之後。大學部約有學生 23,000 人，研究所約有 10,000 人。

本次參訪的土木及環境工程系(Civil and Environmental Engineering, CEE)，共有超過 400 個大學生、360 個研究生、50 位全職教授及 22 位職員，依其研究領域共計分爲 6 個組:

- 營建管理組(Engineering & Project Management Program)
- 環境工程組(Environmental Engineering)
- 大地工程組(Geotechnical Engineering)
- 結構工程、力學及材料組(Structural Engineering, Mechanics and Materials, SEMM)
- 交通工程組(Transportation Engineering)
- 土木系統組(Civil System)

結構工程、力學及材料組(Structural Engineering, Mechanics and Materials, SEMM)爲具有國際卓越名聲的研究團隊，研究領域包括地震工程、結構與固體

力學，及結構和營建材料，與本所材料實驗中心研究領域相近。以下將針對 Davis Hall 及 Richmond Field Station 兩處之重要實驗設備加以介紹。

(a) Davis Hall(照片 25)

(1)結構實驗室(Structures Laboratory)：

- 強力地板：12.5 公尺(41 英尺)×40.2 公尺(132 英尺)
- 油壓致動器(十幾支，載重能力最高可達 500 公噸)
- 多台資料擷取器
- 機械和電子配屬設備

(2)結構動力實驗室(Structural Dynamics Laboratory)：

- 數個小型地震振動台：0.91 公尺(3 英尺)×1.22 公尺(4 英尺)
- 動態致動器
- 高速萬能試驗機
- 強迫和自由振動的監控設備

(3)實驗力學實驗室：

- 6 台萬能試驗機可提供由 27-270 公噸(60-600 kips)載重能力
- 一台軸向扭轉及 Charpy 衝擊測試設備

(4)實驗模型實驗室：

- 強力地板：6.1 公尺(20 英尺×12.2 公尺(40 英尺)
- 加載設備、資料擷取器及附屬設施

(5)非破壞檢測實驗室：結構非破壞性檢測

(6)結構材料實驗室：土木工程材料(如水泥、混凝土、鋼、木以及塑膠)的研究設備

照片 25 Davis Hall 實驗室

(b) Richmond Field Station

因土木及環工系館 Davis Hall 的空間不足，因此於郊外另設置 Richmond Field Station，有通勤巴士可提供柏克萊校區及 Richmond Field Station 之間的交通連繫。

(1)結構研究實驗室(Structures Research Laboratory)

- 強力地板：18.3 公尺(60 英尺)X6.1 公尺(20 英尺)
- 反力構架：18.3 公尺(35 英尺)高
- 萬能試驗機：1816 公噸(400 萬磅)(照片 26)
- 靜態和動態的油壓致動器
- 附屬設備和資料擷取器

(2)防火研究實驗室(Fire Research Laboratory)

- 大尺寸牆和房間/角落火災試驗室
- 多種最新型儀器可進行熱量釋放率，火災延燒及其他火災效應等相關研究

(3)地震振動台(Earthquake Simulator, Shaking Table)(照片 27)

- 於 1972 年設立
- 6.1 公尺(20 英尺)×6.1 公尺(20 英尺)
- 可以提供 6 個維度的加速度

- 試體最大載重：45.4 公噸(100,000 磅)
- 最大水平加速度：1.5 G

(4)大型消能器試驗機(Large Damper Test Machine)(照片 28)

- 動態最大能量：900 kN (200 kips) at 0.38 m/sec (15 in/sec)
- 靜態最大能量：1560 kN (346 kips) with a peak-to-peak stroke limit of (600 mm) 24 in

(5)小型消能器試驗機(Small Damper Test Machine)(照片 29)

- 動態最大能量：445 kN (100 kips) at 0.50 m/sec (20 in/sec)
- 靜態最大能量：peak-to-peak stroke limit of 500 mm (20 in)

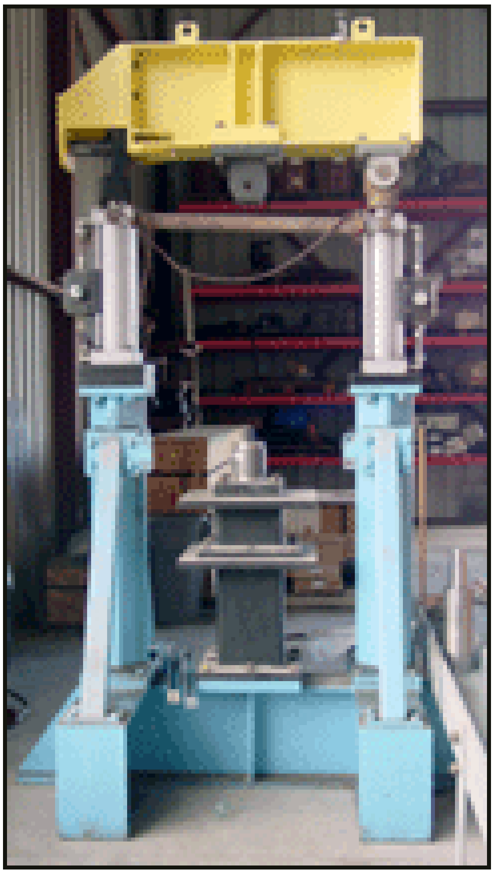
(6)隔震墊試驗機(Expansion Joint Test Machine)(照片 30)

- 動態最大能量：1092 mm/sec (43 in/sec) at 67 kN (15 kips)
- 靜態最大能量：170 kN (38 kips)

照片 26 400 萬磅萬能試驗機

照片 27 地震振動台

照片 28 大型消能器試驗機



照片 29 小型消能器試驗機

照片 30 隔震墊試驗機

照片 31 Richmond Field Station 實驗室材料置放架

照片 32 Richmond Field Station 梁柱試體準備

照片 33 Richmond Field Station 實驗室廢棄試體(1)

照片 34 Richmond Field Station 實驗室廢棄試體(2)

照片 35 Richmond Field Station 實驗室致動器置放架

照片 36 Richmond Field Station 實驗室大門

(二)柏克萊校區建築耐震補強現況

柏克萊校區因有海沃德斷層(the Hayward fault)穿越，校方決定在 20 世紀 70 年代初全面啓動地震安全計劃，其目標是維護其歷史建築，並確保新的建築能抵禦未來可能發生地震。如果不執行此項工作的風險是很高的，如果因爲大地震而關閉校園，對於加州大學和海灣地區的經濟，將有長遠的影響。以下就代表性的 3 棟建築，擇要說明。

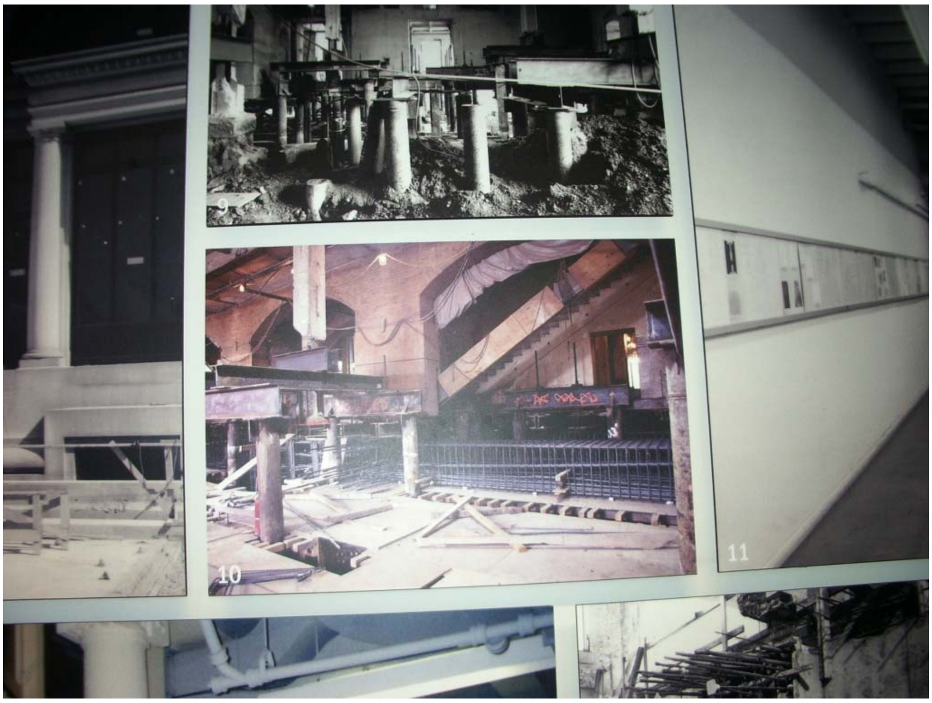
(1) Hearst Memorial Mining Building：本建築僅離海沃德斷層 152 公尺(500 英尺)，採用基礎隔震技術，可以在不影響上部建築內部裝修及營運情況下，補強此歷史建築。(照片 37、38、39)

(2) 圖書館：因此建築爲低層建築，以加裝束制斜撐(BRB)及增設剪力牆進行補強。(照片 40、41)

(3) 化學系館：在不影響上部建築內部裝修及營運情況下，以增設外側剪力牆進行補強。(照片 42)

照片 37 Hearst Memorial Mining Building 補強(1)

照片 38 Hearst Memorial Mining Building 補強(2)



照片 39 Hearst Memorial Mining Building 補強(3)

照片 40 圖書館加裝束制斜撐(BRB)補強

照片 41 圖書館增設剪力牆補強

照片 42 化學系館增設外側剪力牆補強

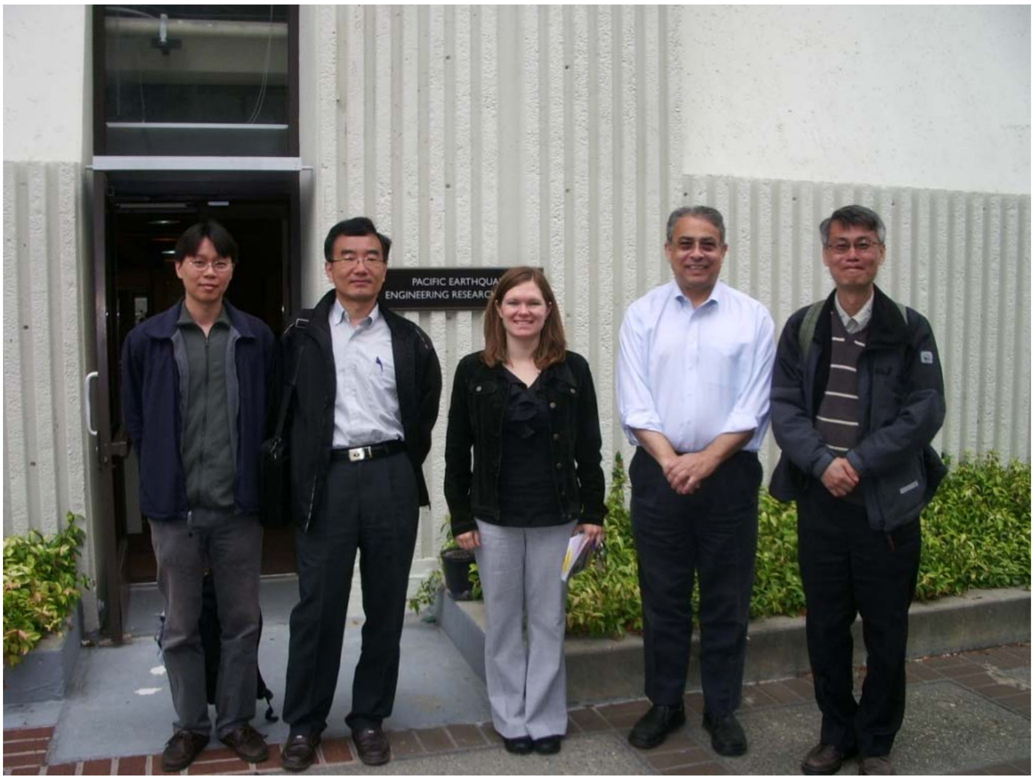
(三)太平洋地震工程研究中心(PEER)

太平洋地震工程研究中心(Pacific Earthquake Engineering Research Center, PEER)總部位於加州大學柏克萊分校，是一個由多家機構參與的學術研究和教育中心。來自超過 20 所大學的學者，數家工程顧問公司，以及各州和聯邦政府機構的研究者，針對結構及大地工程、地質學/地震學、維生管線、運輸、風險管理及公共政策等方面，進行與地震工程相關的研究。

PEER 於 1996 年成立，爲一個 9 所美國太平洋沿岸大學的聯合研究及教育中心，並於 1997 年正式成爲國家科學基金會(Nation Science Foundation, NSF)轄下的工程研究中心。PEER 自 2008 年正式與 NSF 分離，改由聯邦，各州，加州政府以及工業合作機構支持。儘管提供資金者改變，PEER 仍繼續擁有 9 個核心機構，並且積極和全世界各地的研究人員，相關教育工作者、學生和地震專業研究者合作交流。

PEER 研究的目的在於是提供可信的數據、分析模式和軟體工具，以支援以性能爲目標的地震工程學。PEER 研究目前集中於 4 大研究領域包含建築結構系統，橋梁和運輸系統，維生管線系統和資訊技術。

此次參訪由國立臺灣大學土木系蔡克銓教授、柏克萊分校臺灣博士生賴俊維及陳垂欣同學熱心安排，由 PEER 執行長 Dr. Yousef Bozorgnia (Executive Director)進行 1 個小時 PEER 研究現況的簡報，會後並由 PEER Outreach Director Ms. Heidi Faison 親切介紹柏克萊校園建築補強案例，參見照片 43、44。



照片43 參訪PEER(左1：陳垂欣同學，左2：曹源暉主任，中：Ms. Heidi Faison，右2：Dr. Yousef Bozorgnia，右1：李台光研究員)

照片 44 PEER Outreach Director Ms. Heidi Faison 親切介紹校園建築補強案例

參、赴美研習心得及建議事項

(1)美國加州大學聖地牙哥分校之結構工程系，因擁有完整之實驗設施群，近年來在大學排名已逐步攀升，也因為大型力學實驗設備完善，除研究計畫案量維持穩定外，在結構耐震領域亦有舉足輕重之地位，本次參訪與研習行程，得以一窺該系之主要大型力學實驗設施，對未來材料實驗中心在實驗研究之發展，將有實質上之助益。

(2)在實驗操作方面，Powell 實驗設施群皆設有專職之技術師，針對實驗研究案件，研究人員僅規劃實驗計畫，設備架設及實驗操作則由技術師負責，由此，可培育精良之技術人力。本所材料實驗中心在實驗操作方面仍仰賴臨時人力，實驗技術難以紮根，此為日後需調整改善之處。

(3)在實驗室營運維護方面，由於美國加州政府財政困窘，補助州立大學之經費減少，學校實驗室亦須自籌經費才得以運作，因此在人力增補與儀器設備維護方面，亦須撙節開支。本所材料實驗中心主要儀器設備之保固期限陸續到期，未來設備維護費用將逐步提高，除持續爭取科技計畫支援外，檢測業務的擴增亦是需要努力的方向。

(4)本所 3000 噸萬能試驗機之設備容量，目前在世界上仍為數一數二、絕無僅有之實驗設備，在與汪教授之言談間，似乎亦有國際合作研究之空間，因此，除了持續強化實驗室人員在大型力學實驗方面之技術能力外，亦需積極籌畫未來實驗研究之發展目標。

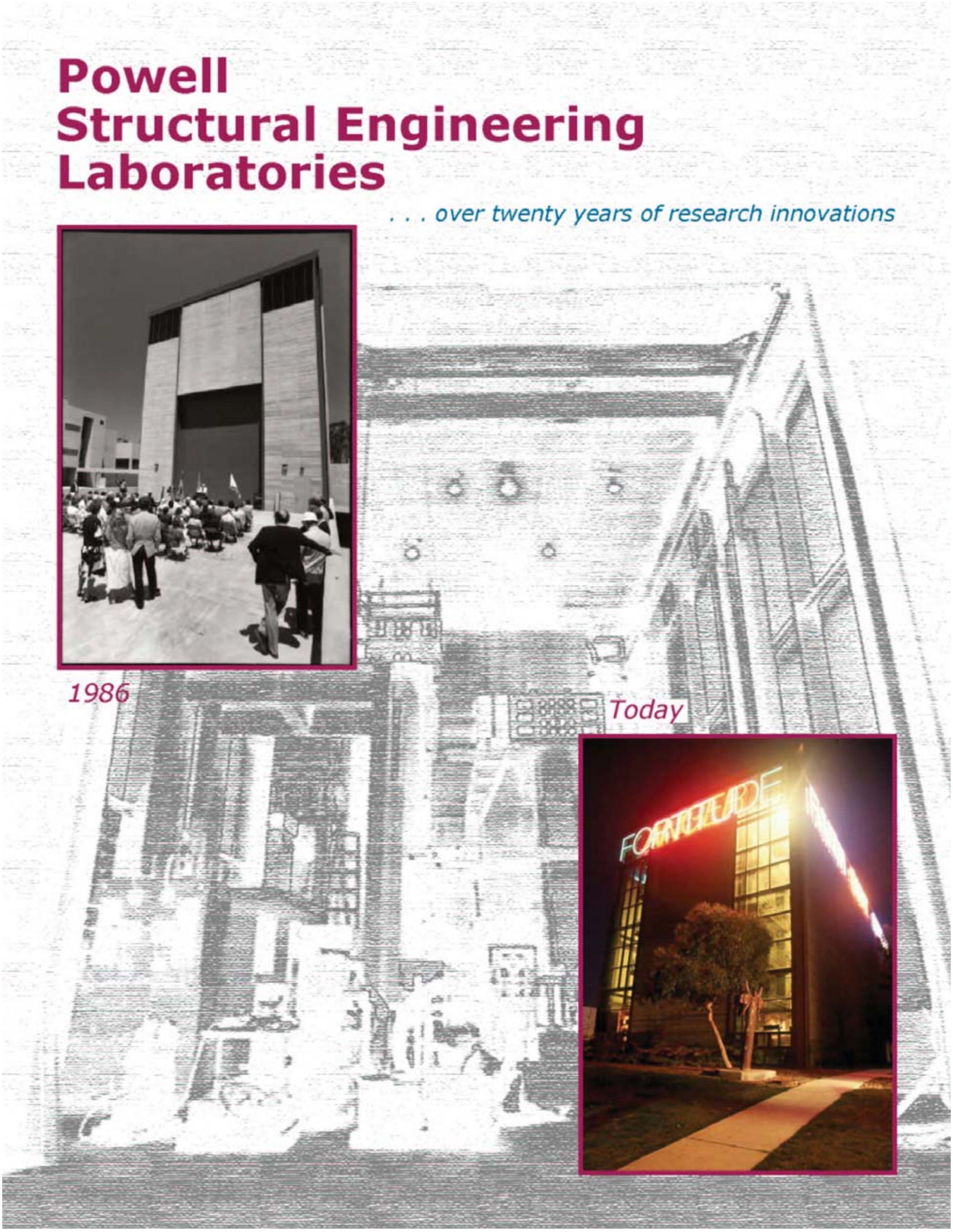
(5)美國加州大學柏克萊分校及太平洋地震工程研究中心(PEER)為國際知名之地震工程研究重鎮，實驗設備與研究課題與本所相近，其相關研究經驗非常值得本所借鏡，應持續實驗研究與營運經驗等方面的交流，以提升本所實驗能力。

(6)本所應藉由國際合作研究的機會，汲取美國知名學者的研究經驗，以拓展本所國際知名度及提昇國際地位。

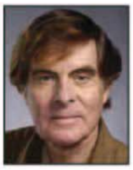
(7)加州大學聖地牙哥分校結構工程系近年來之重點工作，主要以發展大型結構試驗爲主，包含大型橋梁模型之靜態及動態試驗、阻尼器、隔震器及束制斜撐之試驗，此外，其戶外大型振動台可進行大型結構之動態試驗，可做爲本所未來規劃相關研究方向及課題之參考。

(8)柏克萊分校及太平洋地震工程研究中心(PEER)近年來之研究方向，主要集中於 4 大研究領域包含建築結構系統，橋梁和運輸系統，維生管線系統和資訊技術，其研究內容可做爲本所未來規劃相關研究課題之參考。

附錄一、**Powell** 結構工程實驗設施群文宣



Above and on front cover: The Powell Lab's north building features a neon sculpture, "Vices and Virtues" by Bruce Nauman, part of the Stuart Art Collection at the University of California, San Diego. The sculpture was added in 1988.



Gil Hegemier, *Department Chair and Director*
Dr. Hegemier, an internationally recognized expert on protective technologies for civil structures, is the founder of the Powell Laboratories. Dr. Hegemier has been with UC San Diego since 1966.

The Charles Lee Powell Laboratories at UC San Diego are among the largest and most active, full-scale structural testing facilities in the world. With twelve (12) distinct testing facilities, federal and state governments and industry associations rely on the multi-million-dollar Powell facilities for tests to improve seismic hazard mitigation, verify new structural materials and concepts, advance structural safety, and increase the U.S. industry's worldwide competitiveness. Dedicated to research at the materials-, component-, assembly-, and systems-levels, the Powell Labs feature one of the largest assemblies of reaction-wall/strong floor systems in the world. The main testing facility was dedicated in 1986, and includes 12,179 assignable square feet of space. Additional facilities have been added as the scope and nature of Powell Labs research has expanded. With their test area dimensions, load capacities, state-of-the-art computer controlled servo-hydraulics, and data acquisition systems, the laboratories represent a unique tool for large and full scale testing of structures. In 2005, the Englekirk Structural Engineering Center opened as an expansion of Powell Labs (located eight miles from the UC San Diego campus), and is equipped with the world's first outdoor shake table and the country's largest soil foundation-structure interaction facility.

The Charles Lee Powell Structural Engineering Laboratories—

- Structural Systems Laboratory
- Caltrans Seismic Response Modification Device
- Composite Structures Laboratory
- Advanced Composites Manufacturing Laboratory
- Composite and Aerospace Structures Laboratory
- Composite Manufacturing & Characterization Laboratories
- Structural Components Laboratory
- Geomechanics Laboratory/Centrifuge
- Mobile Field Laboratory
- Structural Dynamics Laboratory
- Englekirk Structural Engineering Center
- Non-Destructive Evaluation(NDE)/Structural Health Monitoring (SHM) Laboratories

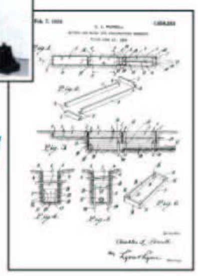
About the Charles Lee Powell Foundation . . .

Charles Lee Powell, third cousin to General Robert E. Lee, was a pioneering, self-taught engineer who invented and patented new methods for building concrete structures underground. He is credited with building much of Los Angeles' early infrastructure. Powell remained committed to a strong work ethic throughout his life, working until his death age 96. As he had only distant relatives, Powell had made provisions in his will for a charitable foundation that would carry forward his legacy of innovation and entrepreneurial spirit.

Since the opening of the first Powell Laboratory in 1986, The Charles Lee Powell Foundation has donated over $24 million in research monies. Additionally, the Foundation continues in the generous, pioneering spirit of Powell in the development of the new UCSD Powell-Focht Biogengineering Hall, completed in 2002.

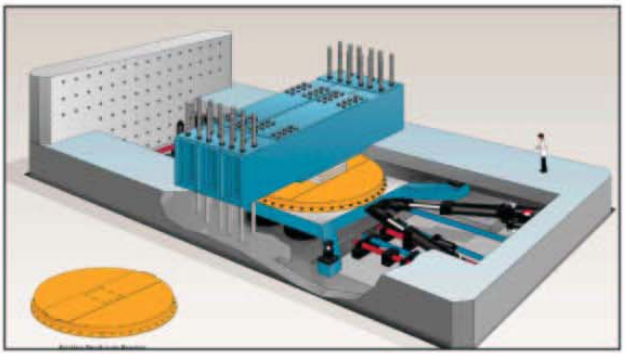
In 2005, the Englekirk Structural Engineering Center became the newest facility of the Powell Laboratories. The Foundation continues to support and endorse the on-going research UCSD's Department of Structural Engineering and the Charles Lee Powell Laboratories, a relationship that is essential and meaningful to the existence and thrive-ability of these research laboratories.

At left: Charles Lee Powell in 1959.



At right: Powell's patent: Method and Means for Constructing Trenches, June, 1925.

Both images courtesy of the Charles Lee Powell Foundation.



Gianmario Benzoni
Research Scientist and Project Manager, SRMD

Seismic response modification devices (SRMDs), such as dampers and isolator bearings, have been recently incorporated into many seismic retrofit strategies, particularly in major toll crossings like the ones object of the Caltrans Toll Bridge Retrofit Program. Capacities and sizes of these devices make problematic the characterization of their performance, longevity and wear. For this reason Caltrans supported the development of this dedicated testing facility, capable of real-time 6-Degrees of Freedom (DOF) dynamic characterizations of full-scale bearing devices and dampers. The facility was completed in 1999 and was developed jointly by the California Department of Transportation (Caltrans), the Department of Structural Engineering at UC San Diego, and MTS Corporation of Eden Prairie, Minnesota. The SRMD Test Facility, occupying over 16,300 sq. ft. of lab/office space, is located directly adjacent to the Powell Structural Research Laboratories, with the advantage of direct access to its support services. Devices never before tested under a full range of forces, displacement and velocities are now tested for applications around the world. The results are used to develop and improve new isolation and energy dissipation techniques, to document the quality of production isolators and dampers, as well as to provide researchers with an unprecedented set of response data obtained from full scale devices. The SRMD was updated in 2003 with a digital tri-variable controller, digital off-line simulation for performance prediction, and can operate in "shaking table" mode (sponsored by FHWA).

The SRMD testing system consists of:

- prestressed concrete reaction frame and a moving platen, connected by four horizontal actuators to the concrete box.
- the platen, 3.658 m wide by 4.750 m long, slides over four hydraulic hydrostatic low friction bearings attached to the floor
- four steel outrigger arms that support four pairs low friction slide bearing actuators
- a removable steel cross beam
- a prestressed reaction wall

Specifications:

COMPONENT	CAPACITY
Vertical Force*	53,400 kN (12,000 kips)
Longitudal Force*	8,900 kN (2,000 kips)
Lateral Force*	4,450 kN (1,000 kips)
Vertical Displacement	+/- 0.127 m (+/- 5 in)
Longitudinal Displacement	+/- 1.219 m (+/- 48 in)
Lateral Displacement	+/- 0.610 m (+/- 24 in)
Vertical Velocity	+/- 254 mm/s (+/- 10 in/s)
Longitudinal Velocity	+/- 1,800 mm/s (+/- 70 in/s)
Lateral Velocity	+/- 760 mm/s (+/- 30 in/s)
Relative Platen Rotation (Roll, Pitch and Yaw)	+/- 2 degrees
Maximum Specimen Height	1.524 m (60 in)

*Based on a minimum System Operating Pressure of 21 MPa

At right (top): The SRMD with a tested bridge bearing; (below) Overlooking the SRMD, located within the High Bay Physics building, on the UC San Diego campus.

Robert and Natalie Englekirk

The Englekirk Structural Engineering Center (ESEC) was certified in 2008 as an "Accredited Testing Laboratory" by the International Accreditation Service, Inc. ESEC is the only testing facility in North America to receive this certification.

A Gift from the Englekirk's

In February, 2005, UC San Diego announced a gift of $1.5 million from structural engineering industry leader Robert Englekirk and his wife, Natalie, to be used to support research and fellowships and scholarships at its Jacobs School of Engineering. Englekirk is the founder of the Englekirk Companies, which has been responsible for the structural design of many impressive construction projects including the Getty Center, the Kodak Theatre, and Horton Plaza. The Englekirk's commitment is primarily directed towards UCSD's new Englekirk Structural Engineering Center. Their gift leverages nearly $17 million in federal and state support for three new testing facilities including the world's first outdoor shake table, the country's largest soil-structure interaction facility, and the world's first blast simulator for studying the effects of bomb blasts and testing technologies to harden structures against terrorist bomb attacks. "It has always been Natalie's and my intention to give back and we have been looking for the right opportunity," said Englekirk. "We chose to support UC San Diego and the Jacobs School of Engineering because they have made structural engineering a priority. UC San Diego is deeply committed to educating the next generation of structural engineering leaders and to promoting meaningful research."

At top: A rendering of the Robert and Natalie Englekirk Structural Engineering Center, located 8 miles east of UC San Diego. Next: The Englekirk Center, as seen from a news helicopter, the subject of recent local and national news coverage. Pictured in the foreground is a full-scale, seven-story building, as constructed in 2005, and tested on the world's only outdoor shake table, to evaluate new reinforced concrete seismic design methodologies. Behind the test structure is the Soil Foundation-Structure Interaction Facility (SFSI). To the right of the test structure is the Blast Simulator facility.

The Englekirk Structural Engineering Center Board of Advisors includes:

American Segmental Bridge Institute • Anderson Drilling • Baumann Engineering • Brandow and Johnston Associates • Burkett and Wong Engineers • Carpenters/Contractors Cooperation Committee • Charles Pankow Builders, Ltd. • Clark Pacific • Douglas E. Barnhart, Inc. • Dywidag-Systems International, USA, Inc. (DSI) • Englekirk and Sabol Consulting Structural Engineers, Inc. • Englekirk Systems Development, Inc. • EsGil Corporation • GEOCON, Inc. • Gordon Forward • Highrise Concrete Systems, Inc. • Hilti • Hope Engineering, Inc. • John A. Martin and Associates • Josephson, Werdowatz & Associates • JVI, Inc. • KPFF Consulting Engineers • Matt Construction Corporation • Morley Builders • Nabih Youssef and Associates • Oak Creek Energy Systems • Occidental Petroleum Corporation • Pacific Southwest Structures • PCL Construction Services, Inc. • Portland Cement Association • Precast/Prestressed Concrete Manufacturers Association of California (PCMAC) • Saiful/Bouquet, Inc. • Schuff Steel—Pacific, Inc. • Simon Wong Engineering • Simpson Manufacturing Company • Smith-Emery Company • Stedman and Dyson Structural Engineers • Structural Engineering Association of San Diego (SEAOSD) • Structural Engineering Association of Southern California (SEAOSC) • The Eli & Edythe L. Broad Foundation • Twining Laboratories • UC San Diego Design and Construction • Verco Manufacturing Co. • Weidlinger Associates, Inc.

Blast Simulator

Recent and continuing terrorist attacks on our building and transportation infrastructure have clearly demonstrated the need to develop and implement blast mitigation and hardening optimization methodologies to protect our interests both at home and overseas. To address these issues, UCSD and funding agency Technical Support Working Group (TSWG) have developed the world's first hydraulic-based simulator to simulate full scale explosive loads without the use of live explosive materials. The simulator is performing fully repeatable, controlled blast load simulations on critical structural elements such as columns, beams, girders, and walls, to characterize the progressive collapse of these structural components and systems when subject to local or short standoff distance charges. It is also being used to investigate the response of bridge components such as decks, piers, and towers to simulated short standoff explosive loads. The blast simulator also simulates longer standoff explosive loads that create debris fields from potentially lethal non-structural components such as windows, masonry walls, and curtain walls. Blast simulator data are validated by comparison with field test data and used in the validation of computational physics models. New and existing blast retrofit designs including commercial off the shelf technologies and fiber reinforced polymer composites are being investigated. Standard test protocols are being developed for product validation.

The blast simulator impacts an as-built reinforced concrete column with an impulse equivalent to a car bomb at curbside. High speed photography captures the failure. In field testing, the explosive fireball prevents viewing the damage progression.

NEES Shake Table

The UCSD-NEES (Network for Earthquake Engineering Simulation) Outdoor Shake Table is capable of creating realistic simulations of the most devastating earthquakes ever and has no height restrictions, thus enabling structural tests which have never been possible before. The facility is part of the National Science Foundation's George E. Brown, Jr. NEES program. At 25 ft. by 40 ft., this is the largest shake table in the United States. Although this table is not the largest of its kind in terms of size in the world, the velocity, frequency range, and stroke capabilities make it the largest table outside Japan, and the world's first outdoor shake table. The facility adds a significant new dimension and capabilities to existing United States testing facilities with no overhead space and lifting constraints.

A 70-ft.-tall, 23,400-lb. wind turbine is subjected to an earthquake simulation on the NEES Shake Table.

Soil Foundation-Structure Interaction Facility (SFSI)

With its refillable soil pits, laminar soil shear box, and two reaction walls, this is the nation's largest facility for testing soil-structure reactions to earthquakes and other natural disasters, such as hurricanes. The reaction walls allow for full-scale testing of systems such as bridge abutments and pile foundations. Also unique to the facility are two soil pits that will enable controlled testing of deep foundations. Researchers will be able to tailor soil properties to simulate conditions in specific geographic locations, and to analyze soil-related phenomena caused by earthquakes such as liquefaction and lateral spreading. The facility is funded by the California Department of Transportation.

Structural Systems Laboratory

Since its opening in 1986, the Powell Labs have been in the forefront of structural testing in the United States. Its 15 m (50 ft) tall reaction wall and 37 m (120 ft) long strong-floor made it the first high bay structural testing facility in the U.S. After the 1989 Loma Prieta earthquake, which caused large amounts of damage in the San Francisco Bay region, Powell Labs lead the way in development and testing of methods to retrofit the existing bridge infrastructure in California, doing the majority of the required testing. The Structural Systems Laboratory has a 15 m (50 ft) high by 9 m (29.5) wide strong wall. It is a two cell box girder structures with a structural depth of 4.72 m (15.5 ft). The strong floor is a four cell box girder 37 m (120 ft) by 15 m (50 ft) wide with a total structural depth of approximately 4.25 m (14 ft). The thickness of the top slab is 0.91 m (3 ft) thick. The usable floor space in front of the strong wall is 30.5 m (100 ft) long. In 1999, a 14.3 m (47 ft) tall by 4 m (13 ft) wide movable reaction tower was added, allowing biaxial testing.

Cal-Trans Segmental Bridge Test

PRESSS 5-story test building

Structural Components Laboratory

Needed expansion in laboratory floor space led to the opening of the Structural Components Laboratories in 1994. That year, the Northridge earthquake caused widespread damage to steel frame buildings, and the Powell Labs again lead in testing of methods to retrofit existing steel structures and methods of construction for new steel structures. The Structural Components Lab has a 9 m (30 ft) high by 19 m (62.3 ft) wide reaction wall which is 1.1 m (3.5 ft) thick. The total floor area is 14.3 m (47 ft) long by 21.3 (70 ft) wide and is a six cell box girder. The usable floor space in front of the reaction wall is 11.3 m (37 ft) long by 15 m (50 ft) wide. The total depth of the strong floor is approximately 4.25 m (14 ft) with a top slab 0.91 m (3 ft) thick and a uniaxial shake table 4.9 m (16 ft) long by 3 m (10 ft) wide. This shake table is recessed into the strong floor in front of the reaction wall.

Composite Structures Laboratory

Also opened in 1994, the Composite Structures Laboratory has a 9 m (30 ft) high by 5.5 m (18 ft) wide reaction wall which is 0.61 m (2 ft) thick. The total floor area is 14.3 (47 ft) long by 7.2 m (23.5 ft) wide. The usable floor space in front of the reaction wall is 12.2 m (40 ft) long by 6.4 m (21 ft) wide. The strong floor is a 0.61 m (2 ft) thick reinforced concrete slab.

Geomechanics Laboratory

This geotechnical centrifuge is used to conduct model tests to study geotechnical problems such as the strength, stiffness and capacity of foundations for bridges and buildings, settlement of embankments, stability of slopes, earth retaining structures, tunnel stability and seawalls. The centrifuge is located in the High Bay Physics Building, adjacent to the Caltrans SRMD Test Facility.

Additional Testing Equipment . . .

These impressive laboratories would be of little use without the appropriate testing equipment, and the list of available equipment is extensive. This includes approximately 2,000 channels of data acquisition and signal conditioning, 29 servo controlled hydraulic actuators ranging in load capacity from 222.4 kN (50 kips) to 2224 kN (500 kips) and from 152.4 mm (6 inch) to 1219 mm (48 inch) in stroke capacity, hundreds of transducers including displacement transducers, rotation transducers, pressure transducers, strain gages, accelerometers and load cells. The actuators are operated by state-of-the-art computerized controllers.

Structural Dynamics Laboratory

The Structural Dynamics Laboratory is a world-class test/analysis facility for characterizing the vibration and/or structural dynamic behavior of complex structures. The centerpiece of the laboratory is a Polytec Scanning Laser Doppler Vibrometer. This instrument, which is noncontacting and not affected by environmental conditions, can measure an extremely broad velocity range (0.1 mm/sec to 10 m/sec) of up to 256,000 (512 x 512 grid) points over a broad field of view (+/- 20 degrees) and dynamic range (0-250 KHz) for specimens located from 20 cm to 75 meter away. Other measurement devices include accelerometers, acoustic microphones, and force transducers. Structural excitations include acoustic speakers, impact hammers, and electro-mechanical shakers ranging (4 to 30 lbs). Data acquisition is controlled by either a 2- or 16-channel HP system (MIMO testing). Data analysis (modal parameter estimations: frequencies, modes, damping) and model correlation is performed using either LMS CADA-X or SDRC IDEAS. A broad range of structures have been tested in all disciplines of structural engineering, including; aerospace (wing-box, satellite reflectors/antenna, fan and propeller blades, missile components, helicopter fuselage), sports (tennis rackets, golf, bicycle frames, America's cup sailboat, CART race car components), and civil (metallic and composite military and civilian bridges).

Composites and Aerospace Structures Laboratory

Composites Manufacturing

This facility deals mainly with graphite/epoxy prepreg and includes a manufacturing lab, a walk-in freezer, autoclaves, and a hot-press.

Computation Mechanics

Extensive finite element modeling and analysis is carried out here, as well as a material composites database program and web page development.

Vibrations Testing

A scanning laser vibrometer is used to perform damage detection studies and to validate analytical models of structures. Shakers, acoustical excitation equipment, hammers, and accelerometer are also available.

Advanced Composites Laboratory

The Advanced Composites Laboratory is dedicated for the development and testing of polymer matrix composite structures.

Students preparing a UAV wing for testing

Crack-detection testing on a railroad in Gettysburg, Pennsylvania.

Non-Destructive Evaluation/Structural Health Monitoring (NDE/SHM) Laboratory

The NDE/SHM Laboratory hosts experimental and computational facilities dedicated to the health monitoring of structural components and structural systems. Methods investigated include non-contact NDE techniques for high-speed inspections and structural health monitoring techniques based on permanently-attached sensors. Work in the laboratory is both experimentally and numerically based. Salient equipment available in the NDE/SHM Lab include: three vibration-isolated tables, two high-power Q-switched Nd:YAG lasers, various CW lasers and interferometers, several high-speed data acquisition systems, full collection of acoustic/ultrasonic transducers including piezoelectric, air-coupled and magnetostrictive sensors, two RITEC systems for high-power ultrasonic testing, 8-channel Acoustic Emission system, modal testing equipment and two high-speed (1000 fps) digital cameras.

Above: At the 1986 grand opening ceremonies of the Charles Lee Powell Laboratories (CLPL), is Gil Hegemier (founding and current CLPL Director), Lea Rudee (founding Dean of Jacobs School of Engineering and Professor Emeritus, Charles W. Rees, Jr. (then President of the Board of Directors, CLP Foundation), Frieder Seible (founding Department Chair, CLPL Designer, and current Dean of Jacobs School of Engineering), Ralph Richey (Daly Corporation), and Richard Atkinson (then UCSD Chancellor).

Below: Powell South Lab

Left: Powell North Lab, at night

Left: The High Bay Physics Building, home of the Seismic Response Modification Device, with tested columns in foreground.

UCSD

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附錄二、UCSD 結構工程系研究計畫

The Department of Structural Engineering @ UC San Diego . . .

Founded in 1997 as an off-shoot of Applied Mechanics and Engineering Sciences, the Department of Structural Engineering at UC San Diego has enjoyed thirteen years of growth and success. Our mission is to provide a comprehensive education and training to engineers using a holistic approach to structural systems engineering by emphasizing and building on the commonality of engineering structures at the levels of materials, mechanics, analysis and design.

Powell Labs...Over Twenty Years of Research Innovations . . .

The Charles Lee Powell Laboratories were dedicated in 1986, with the Engelkirk Structural Engineering Center added in 2005. The multiple-location, multi-million-dollar labatories are committed to research at the materials, component, assembly, and systemslevels, and features one of the largest assemblies of reaction wall/strong floor systems in the world. The Englekirk Structural Engineering Center, a one-of-a-kind facility, is enabling structural tests that have never been possible before. The Center is equipped with the world's first outdoor shake table, adjacent to the country's largest soil-structure interaction facility, allowing researchers to perform dynamic earthquake safety tests on full-scale structural systems. The Center's blast simulator is used to study the effects of bomb blasts and to test new technologies to harden buildings against terrorist bomb attacks.

Patrick J. Fox Joins SE Faculty . . .

P. Fox

The Department of Structural Engineering is pleased to announce the appointment of Dr. Patrick J. Fox in 2009 to Professor. Dr. Fox will begin teaching in Winter 2010, is now affiliated with Muir College. Dr. Fox joins UC San Diego from Ohio State University where he served as Professor in the Civil & Environmental Engineering & Geodetic Science since 2003. Previous to Ohio State, Dr. Fox was on the faculties of UCLA and Purdue University. Dr. Fox obtained his Ph.D. degree in Civil & Environmental Engineering at the University of Wisconsin-Madison in 1992. His areas of specialization are geotechnical and geoenvironmental engineering, with emphases in slope stability, groundwater, contaminant transport, landfills, geosynthetics, retaining structures and soil dynamics. Dr. Fox has published over 120 technical papers on his research. He has won numerous awards for teaching and research, including the prestigious Arthur Casagrande Professional Development Award and the Thomas A. Middlebrooks Award (twice) from the American Society of Civil Engineers (ASCE), the IGSAward from the International Geosynthetics Society, the Chandra S. Desai Excellent Contributions Medal from the International Association for Computer Methods and Advances in Geomechanics, and best paper awards from the International Journal of Geomechanics and Geotechnical Testing Journal. He is currently Editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering, Editorial Board Member for Geosynthetics International and the ASCE International Journal of Geomechanics, Chair of the Technical Publications Committee of the ASCE Geo-Institute, and Chair of the upcoming GeoFlorida 2010 ASCE GeoCongress. Dr. Fox is a licensed Professional Engineer in the State of Ohio.

About Our Degree Programs . . .

UC San Diego's Department of Structural Engineering offers B.S., M.S., and Ph.D. degrees. Our programs and curricula provide education and training through a holistic approach to structural engineering by emphasizing and building on the commanalities in materials, mechanics, and analysis considerations across the disciplines of civil, aerospace, and marine engineering. Our programs feature strong components in laboratory experimentation, basic theory, information technology, and engineering design. For admissions information, contact Graduate Student Affairs Advisor, Ms. Debra Bomar (dbomar@ucsd.edu; 858-822-1421), or Undergraduate Student Affairs Advisor, Ms. Danielle Swenson (dswenson@ucsd.edu; 858-822-2273).

The Class of 2009 (B.S. Program)

Blast Resistant FRP Composite Designs & Verification

Principal Investigator: Professor Robert Asaro
Co-Principal Investigators: Professors Gil Hegemier & Hyonny Kim

Professors Asaro, Hegemier and Kim are working with the Office of Navy Research on concept designs of the new DDX deckhouse-steel connections, related to the U.S. Navy's newest class of destroyers, the DDG 1000. Hybrid joints are subject to complex internal stress states and are critical in terms of how they transfer loads between the massive steel hull structuresstructures and the lower density fiber reinforced polymer (FRP) composite deckhouse structure - - these researchers have impressive experience in this area. In addition to the study of joints, another team is evaluating blast damage vulnerability of the deckhouse structure. The Navy has plans for the production of three DDG 1000's.

Lightweight Composite Portable Bridges for Military and Emergency Applications

Principal Investigator: Professor John Kosmatka

The need for immediate mobility in the aftermath of natural disasters, or on the battlefield, has lead to the development of light-weight bridging composed of aerospace composite materials. At UC San Diego, a broad multi-disciplinary research program is underway on the design, analysis, fabrication, and testing of these large (20-40 m) structures capable of supporting 100-ton vehicles. Improved composite manufacturing methods are leading to innovative structural solutions.

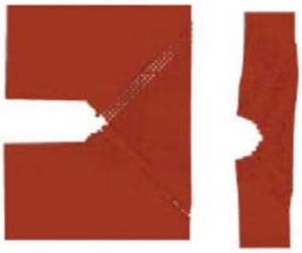
Simulating Bomb Blasts

Principal Investigator: Professor Gilbert Hegemier

The Explosive Loading Laboratory and Testing Program, funded by the Technical Support Working Group (TSWG), is the first program in the world to develop a hydraulic-based blast simulator to simulate full scale, live explosive events up to 3000 psi-msec without the use of explosive materials or a fireball. Energy deposition, which takes place in time intervals of 2 to 4 ms, is accomplished via an array of ultra-fast, computer controlled hydraulic actuators with a combined hydraulic/high -pressure nitrogen energy source based on blast physics models and codes. The blast simulator has been validated through comparison with the live explosive field test data, and computational blast physics models and codes are being improved and validated using the blast simulator and field test data. The simulator is being used to generate high fidelity data on the response and failure processes associated with critical infrastructure components subject to explosive loads, to evolve effective blast hardening/protective methodologies for existing and new structures, and to standardize test protocols for product validation. The simulator performs fully repeatable blast load simulations on structural elements such as columns, beams, girders, and walls; on nonstructural elements such as windows, masonry walls, and curtain walls; and on bridge components such as decks, piers, and towers. Testing results are viewed by still shots taken by three ultra high-speed Phantom cameras, each capable of capturing 5,000-10,000 frames per second!

Testing Biomineralized Composites for Greater Toughness

Principal Investigator: Professor Robert Asaro

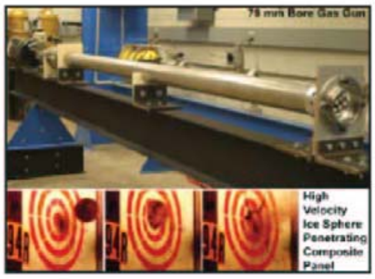


Are biomineralized composites tougher due to their nano-scale size? Atomistic studies of the resistance to crack propagation in nano-sized ceramic platelets that exist in teeth, bone, or the shells of mollusks, reveal that they are far more ductile than their bulk counterparts. The principal reasons are concerned with the increased ease of crack tip blunting and the inability for cracks to sustain the stress concentration required for brittle fracture. Examples of crack tip response are shown for cracked plates of thickness 4 nm and 16 nm, subjected to uniaxial tension; the former displays ductile rupture whereas the latter demonstrates more brittle-like crack growth. At left, cross-sections of cracked plates with thickness 16 nm (far left) and 4 nm (left) show crack propagation in the 16 nm thick plate and crack tip blunting in the 4 nm thick plate due to profuse dislocation nucleation.

High Velocity Impact on Composite Structures

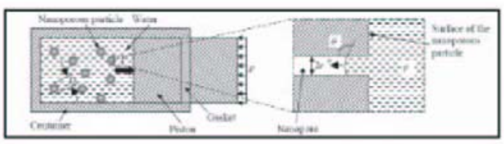
Principal Investigator: Professor Hyonny Kim

High performance composite aircraft structures are exposed to various impact threats such as bird, hail, ice, and ground maintenance damage. Ongoing research projects are particularly focused on the development of damage to carbon and glass epoxy structures as a result of impact by hailstones traveling at high velocities, e.g., equivalent to aircraft flight speeds. A gas gun is used to launch ice projectiles onto composite test panels to determine the threshold at which impact damage develops in the structure, thereby defining the resistance of these structures to the formation of damage under such threats. Such tests are also used to determine the morphology of the resulting damage. This latter information is critical in the definition of the impact-created flaws that the aircraft structure must be tolerant to since impact damage to composites is often difficult to detect.



Developing High-Performance Energy Absorbing Liquids

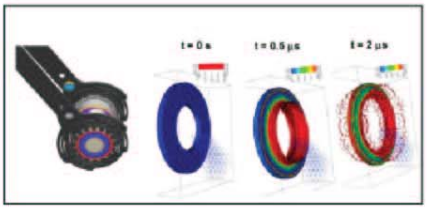
Principal Investigator: Professor Yu Qiao



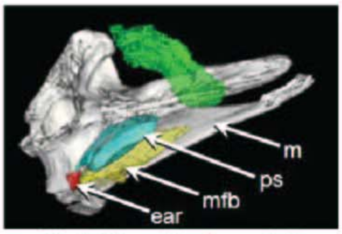
By immersing nanoporous materials in a non-wetting liquid phase, the system becomes an energy absorbing liquid, or a "liquid super-sponge." When sufficient high pressure is applied, the liquid can be forced into the nanopores, leading to a significant energy dissipation characteristic. Prof. Qiao and other UC San Diego researchers are exploring ways that these liquids can be used for protection and damping applications, such as liquid armors, health care products, and protective layers for buildings.

Micromechanical Analysis of Fragmentation using ALE-AMR

Principal Investigator: Professor David J. Benson



Fragmentation is a fundamental process that naturally spans micro to macroscopic scales. Recent advances in algorithms, computer simulations, and hardware enable us to connect the continuum to microstructural regimes in a real simulation through a heterogeneous multiscale mathematical model. We apply this model to the problem of predicting how targets in MegaJoule-class laser chambers dismantle, so that optics and diagnostics can be protected from damage. The mechanics of the initial material fracture depend on the microscopic grain structure. In order to effectively simulate the fragmentation, this process must be modeled at the subgrain level with computationally expensive crystal plasticity models. However, there are not enough computational resources to model the entire laser target at this microscopic scale. In order to accomplish these calculations, a hierarchical material model (HMM) is being developed. The HMM allows fine-scale modeling of the initial fragmentation using computationally expensive crystal plasticity, while the elements at the mesoscale can use polycrystal models, and the macroscopic elements use analytical flow stress models. The HMM framework is built upon an adaptive mesh refinement (AMR) capability. Figure: Fragmentation of a cooling ring in an inertial confinement fusion experiment using the ALE-AMR code.



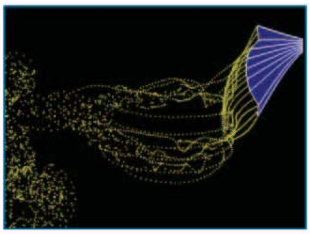
Acoustic Pathways Revealed: Simulating Sound Reception in Cuvier's Beaked Whale

Principal Investigator: Professor Petr Krysl

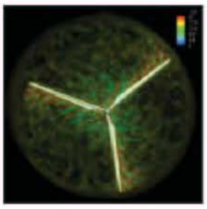
In this collaborative research with San Diego State University's Department of Biology and with Scripps Institution of Oceanography, a finite element vibroacoustic toolkit was applied to the sound transmission in the head of a beaked whale. The model is based on CT data sets as well as physical measurements of sound-propagation characteristics of actual tissue samples. FEM results concern pathways by which sounds reach the ears. Simulations are revealing a previously undescribed 'gular pathway' for sound reception in this species. Propagated sound pressure waves enter the head from below and between the lower jaws, pass through an opening created by the absence of the medial bony wall of the posterior mandibles, and continue toward the bony ear complexes through the internal mandibular fat bodies. This new pathway has implications for understanding the evolution of underwater hearing in beaked whales; this model also provides evidence for receive beam directionality, off-axis acoustic shadowing and a plausible mechanism for the long-standing orthodox sound reception pathway.

Bio-inspired Engineering about Fish Fins

Principal Investigator: Professor Qiang Zhu



The fins of a fish are often strengthened by embedded rays, and therefore possess anisotropic flexibility. Tendons and muscles attached to these rays also allow the fish to actively control the motion and deformation of its fins. This design greatly enhances the efficiency of fish locomotion. Dr. Zhu is concentrating on numerical characterization of the structure versus function of these bio-structures. The eventual application will be bio-inspired propulsion systems.



Fluid-Structure Interaction of Wind Turbines

Principal Investigator: Professor Yuri Bazilevs

The rising costs and highly fluctuating prices of oil and natural gas, as well as their constantly diminishing supplies worldwide create the need for cheaper, sustainable alternative energy sources. Wind turbines that harvest wind energy and convert it to electrical power are such an energy source, playing an increasingly important role and receiving much attention from governments and industry around the world. Wind turbines present several substantial engineering challenges and would greatly benefit from the use of advanced predictive simulation tools. Computational analysis plays a key role in the design and analysis of complex engineering systems. Automobile crash analysis, as well as the design and evaluation of commercial and military aircraft, routinely use advanced computational tools. As such, wind turbines should not be an exception. Regretfully, advanced high-fidelity computational methods for wind turbine analysis that are capable of addressing the above mentioned issues are notably lacking. In this work, we directly address this deficiency by jump-starting, taking leadership in, and setting the standard for computational fluid-structure interaction research and education on wind energy applications world wide. This work is a collaborative work with Professor Benson (UC San Diego), Dr. Tayfun Tezduyar (RICE), and Professor Gil Hegemier (UC San Diego). At left is a three-dimensional simulation of a full-scale wind turbine rotor. The blade diameter is 120 m, the wind speed is 15 m/s, and the rotation rate is 10 RPM. These are typical operating conditions for off-shore wind turbines, which are more severe and challenging to compute than in-land designs. This preliminary computation makes use of over 2,000,000 second-order NURBS isogeometric elements and 90 processors on a Dell PowerEdge Cluster.

How to Shake 1 Million Pounds of Concrete

Principal Investigator: Professor Jose Restrepo

SE researchers spent three months rigorously conducting earthquake simulation tests on a half-scale, three-story structure, and are analyzing the results to be used in the future designs of buildings (parking garages, college dormitories, hotels, stadiums, prisons, and increasingly, office buildings) across the nation. Precast concrete, which is built in pieces and then put together to construct buildings, has been a breakthrough in the industry in terms of saving both time and money and increasing durability. While precast concrete has proven to be a robust design material for structures, researchers are working to provide the industry with new methods of connecting these pieces more efficiently. Researchers produced a series of earthquake jolts as powerful as magnitude 8.0 on a structure resembling a parking garage. The 1 million-pound precast concrete test structure had the largest footprint of any structure ever tested on a shake table in the United States. The $2.3 million research project is a collaboration between UC San Diego, the University of Arizona, and Lehigh University. It is funded by the Precast/Prestressed Concrete Institute and its member companies and organizations, along with the National Science Foundation, the Charles Pankow Foundation and the Network for Earthquake Engineering Simulation (NEES).

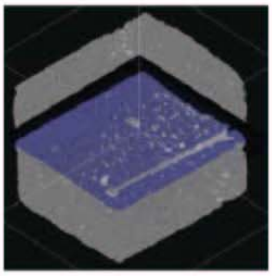
San Francisco-Oakland East Bay Bridge Replacement Project: Precast Prestressed Concrete Skyway

Principal Investigator: Professor Frieder Seible

Dr. Seible led the proof-testing of the new San Francisco-Oakland East Bay Bridge, including the 2.5 km long precast-prestressed concrete skyway (pictured at left). Joints between superstructure segments and the skyway piers were tested at 1/4 scale under simulated seismic loads to establish performance limit states.

Concrete Damage-Transport Properties Correlations

Principal Investigator: Professor Tara Hutchinson



Concrete is by far the most widely-used building material in the United States, with extensive use in the construction of our nation's buildings, highways, tunnels, water supply and sewage systems and other infrastructure. The strong dependency of the service life of concrete on its transport properties means that investigations of the performance of concrete components need to link these transport properties to observed damage states. In collaboration with Los Alamos National Laboratories and supported by the National Science Foundation, Prof. Hutchinson and other UC San Diego researchers are developing damage-transport property correlations, using an integrated program of structural testing of concrete components, gas permeability testing, and X-ray computed tomography (see 3-D reconstruction at right).

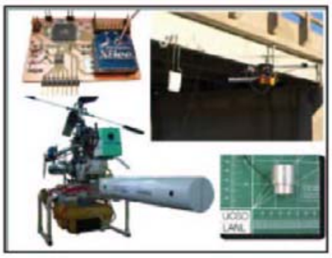
Improving Seismic Performance of Concrete and Masonry Structures

Principal Investigator: Professor P. Benson Shing

Assessing the seismic performance of older reinforced concrete (RC) frames that have masonry infill walls presents a most difficult problem for structural engineers. Currently, there are no reliable engineering guidelines. In a collaborative project sponsored by the National Science Foundation (NSF) under the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program, Professor Shing is leading an effort to develop advanced computational models as well as simplified analytical methods to assess the performance of these structures, and to develop practical and effective techniques based on innovative materials to improve their seismic performance. Final proof-of-concept tests are being conducted on a full-scale three-story RC frame, using the Large High Performance Outdoor Shake Table (LHPOST) at UC San Diego. Strength design of reinforced masonry (RM) structures has been under continuous development and evolution for many years. With structural design moving toward a performance-based approach, research is needed to have a better understanding of the performance of RM structures under different earthquake levels and to develop reliable predictive tools. Professor Shing is working on a second collaborative project sponsored by NSF's NEES program and the masonry industry and led by the University of Texas at Austin. The project involves large-scale testing on the LHPOST and computational simulation.

Advanced Sensor Networking Paradigms and Data Processing for Autonomous Structural Assessment

Principal Investigator: Professor Michael Todd

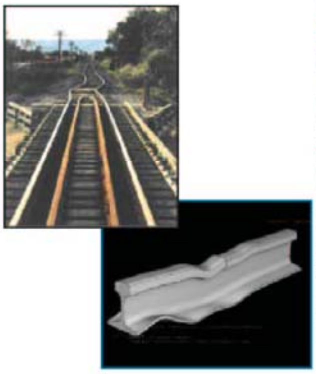


Damage assessment of large-scale structures (e.g., bridges, buildings, or dams) after an extreme event such as an earthquake or a blast load is a challenging task. In many cases, critical damage is not visible or obvious, human inspection poses serious life-safety concerns, and downtime for the structure results in large economic losses. Dr. Todd and other researchers at UC San Diego, with partners in the Computer Science and Engineering Department, California Institute for Telecommunications & Information Technology (Calit2), and the Los Alamos National Laboratory, are developing components for a new systems approach that combines Radio-Frequency Identification (RFID) -based wireless sensing, advanced networking and embedded system architectures, and autonomous network interrogation via unmanned platforms such as robots or unmanned UAV. The unmanned platforms are programmed to move to and query these wireless sensor networks and compute features that would facilitate structural health assessments after such extreme events.

Bridge and Traffic-Pattern Monitoring

Principal Investigator: Professor Ahmed Elgamal

Information technologies are increasingly allowing for advances in monitoring and analysis of structural response. An integrated structural health monitoring analysis framework encompassing data acquisition, database archiving, and model-free/model-based system identification/data mining techniques has been created toward the development of practical decision-making tools. Bridge testbeds at UC San Diego are serving as an environment for the development of such integrated structural health monitoring technologies. Instrumentation includes accelerometers and strain gages for measuring the bridge spatial response, as well as video cameras for tracking the related vehicle traffic. A hardware and software setup records synchronized video and sensor data, and allows real-time Internet transmission and data archiving. Image processing techniques are used to translate the recorded video into corresponding load time histories. Machine learning techniques are employed to correlate the input traffic excitation to the output bridge response. Anomalies in this correlation may be used as a basis for structural health monitoring and related decision making applications.



Rail Monitoring Systems

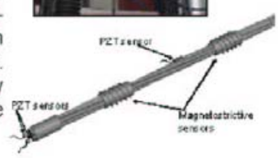
Principal Investigator: Professor Francesco Lanza di Scalea
Co-Principal Investigator: Professor Chia-Ming Uang

Railroad infrastructure is in need of technologies able to prevent derailments and perform repairs/replacements in a timely manner. Due to heavy tonnage and aging conditions, several structural problems affect railroads today, including the growth of cracks hidden from the surface of the rail. Professor Lanza di Scalea and his post-doctorals, Stefano Coccia and Ivan Bartoli, are working with the Federal Railroad Administration (FRA) to develop a system which can detect cracks in rails while in motion, using ultrasonic waves and non-contact (laser) probing to detect the flaws. Additionally, in another FRA project, Professors Lanza di Scalea and Uang are studying ways to detect incipient buckling of rails. Lateral buckling, a severe problem since the advent of continously-welded rail, is one of the most frequent causes of derailments worldwide today. UC San Diego researchers will extract high- and low-frequency dynamic signatures of rails in a non-contact manner as indicators of imminent buckling. Plans are for the development of an incipient buckling detection prototype working in motion at regular train speeds.

Health Monitoring of Post-Tensioned Concrete Bridges

Principal Investigator: Professor Francesco Lanza di Scalea

Ninety-percent of California's bridges are post-tensioned concrete structures. There is a need to develop technologies able to monitor the state of health of the prestressing tendons which carry most of the loads. Recent bridge collapses have further highlighted the problem of the deteriorating conditions of the transportation infrastructure which require information on weak components. Professor Lanza di Scalea and post-doctorals Ivan Bartoli and Salvatore Salamone are working with Caltrans to develop an ultrasonic-based monitoring system for the prestressing tendons of post-tensioned concrete structures. The method is based on embedded sensors and ultrasonic guided waves which can provide information on the level of stress as well as the presence of defects such as corrosion or broken wires. Laboratory tests have indicated the suitability of the guided-wave method to achieve these goals. If further laboratory tests are favorable, the tendon monitoring system will be installed and tested on an operational post-tensioned bridge in California.



System and Damage Identification of a Seven-story Reinforced Concrete Building Slice Tested on the UCSD-NEES Shake Table

Principal Investigator: Professor Joel P. Conte

A full-scale, seven-story reinforced concrete building slice was tested on the UCSD-NEES shake table. Six different state-of-the-art system identification algorithms including three input-output and three output-only methods were used to estimate the modal parameters (natural frequencies, damping ratios, and mode shapes) based on the measured response of the building subject to ambient as well as white noise base excitations at different damage states. The identified modal parameters obtained using different methods were compared to study the performance of these system identification methods, and also to investigate the sensitivity of the estimated modal parameters to actual structural damage. The results obtained in this study were then used to identify damage in the building based on a sensitivity-based finite element (FE) model updating algorithm. The damage identification results were verified through comparison with the actual damage observed in the test structure. Furthermore, the performances of the three output-only system identification methods as well as the FE model updating for damage identification were (numerically) investigated due to variability of different input factors such as amplitude of input excitation, spatial density of measurements, measurement noise, length of response data used in the identification process, and the modeling error.

NEES

The NEES Data Model and NEEScentral Data Repository: A Framework for Data Collaboration in Support of Earthquake Engineering Research

Principal Investigator: Professor Lelli Van Den Einde

The George E Brown Jr. Network for Earthquake Engineering Simulation (NEES) is a shared national network of 15 experimental facilities, collaborative tools, a centralized data repository, and earthquake simulation software, all linked together to enable engineers to develop better and more cost-effective ways of mitigating earthquake damage. To support data organization, archiving and dissemination resulting from NEES related research, the NEES Cyberinfrastructure Center (NEESit) has developed a central data repository (NEEScentral) to capture important reservoirs of data and expose them to the community where their useful lifetime can be extended. NEEScentral provides a centralized location for researchers to securely organize, store, and share data and metadata in a nonproprietary format that can be used in data manipulation and visualization tools. To define the structure by which NEES experiment data are organized, the NEES Data Model was developed, which represents classes of entities and relationships to provide essential data for reproducing experimental and computational simulation results. It is based on a hierarchical structure, consisting of Projects, Experiments, Trials and Repetitions, that collects highly detailed information from each experiment or computational simulation in order to be able to reproduce the research. The NEEScentral Data Repository and supporting data model provide a data management infrastructure to shorten the gap between research and practice through long-term preservation and sharing of data. The ultimate goal is to provide access to different types of experimental and computational data to promote and facilitate collaborative and interactive processes required to address the complex nature of seismic events and their physical and societal impacts, ultimately reducing vulnerabilities from earthquakes.

Load Testing on Boeing's 787 Landing Gear Components

Principal Investigator: Professor Hyonny Kim; Co-Principal Investigator: Dr. Gianmario Benzoni

Professor Kim and Dr. Benzoni recently conducted the Federal Aviation Administration (FAA) certification testing of landing gear components for the new Boeing 787 aircraft. These components were made by Messier-Dowty using advanced composite materials. The parts were subjected to loads exceeding 1 million pounds using the Powell Lab's unique Seismic Response Modification Device (SRMD) test facility, of which Dr. Benzoni is the Project Manager.

Virtual Vecchio: Creating a Digital Clinical Chart for a Landmark Building of the Renaissance

Principal Investigator: Professor Maurizio Seracini; Co-Principal Investigator: Professor Falko Kuester

Professors Seracini and Kuester are developing a "digital clinical chart" for the Palazzo Vecchio in Florence, Italy, part of Calit2's cultural heritage preservation initiative. Their team spent two months in 2007 and 2008 laser-scanning and imaging the interior of the Palazzo's main hall. The goal: to understand the structure's performance and changes over time, and hopefully, to help find Leonardo da Vinci's long-lost masterpiece mural, "The Battle of Anghiari." They have created an interactive 3-D model based on 60 gigabytes of data collected in Florence, including x-y-z coordinates for 2.5 billion points generated from the laser scans in combination with color values for each point, based on giga pixel photography. This model serves as the baseline and reference for a broad range of multi-spectral imaging techniques that already have been acquired, such as GPR (Ground Penetrating Radar), Thermography, NIR (Near Infrared Reflectography), mmw and THz Tomography. Professor Kuester's team is currently developing algorithms and techniques needed to visualize and analyze this massive model, on the 286-million-pixel resolution HIPerSpace display, the highest-resolution such display in the world. Additionally, the team is studying the Palazzo Medici to better understand its history, structural integrity and hidden treasures. This research is made possible, in part, through generous support by SE's Adjunct Professor, Robert Englekirk, and his wife, Natalie, along with Paul and Stacy Jacobs, Sandra Timmons, Richard Sandstrom, and the Chancellor's Interdisciplinary Collaboratories Fund.

Structural Engineering Faculty


Professor Robert J. Asaro, Ph.D.—Experimental and computational studies of nonlinear material behavior. Marine civil structural design. Advanced structural materials.


Assistant Professor Yuri Bazilevs, Ph.D.—Fluid-structure interaction. Vascular blood flow. Turbulence. Isogeometric analysis.


Professor David J. Benson, Ph.D.— Computational mechanics. Solid mechanics. Materials Science.


Professor Joel P. Conte, Ph.D.—Structural reliability and risk analysis. Probabilistic design. Computational structural mechanics. Experimental structural dynamics. System identification. Structural health monitoring.


Professor Ahmed Elgamal, Ph.D.— Health monitoring sensor networks, database and data mining applications. Computational and experimental simulation of soil/structure systems. Seismic load mitigation solutions.


Adjunct Professor Robert Englekirk, Ph.D., P.E.—Reinforced concrete. Design of buildings and bridges. Seismic response of mid-rise buildings. Large-scale structural analysis and design.


Adjunct Professor Charles Farrar, Ph.D.—Integrated approaches to Structural Health Monitoring. Damage detection. Damage prognosis technologies and solutions.


Professor Patrick J. Fox, Ph.D., P.E.—Geotechnical and geoenvironmental engineering. Slope stability. Retaining structures. Foundations. Soil dynamics. Settlement. Groundwater. Landfills. Geosynthetics.


Professor and Chair Gilbert Hegemier, Ph.D.—Blast mitigation. Mechanics of composite materials with applications to aerospace and civil structures. Infrastructure renewal via composites. Large-scale experiments on structures.


Associate Professor Tara Hutchinson, Ph.D., P.E.—Experimental and analytical studies in earthquake engineering. Seismic performance assessment of structures. Soil-structure interaction. Seismic response of concrete and timber structures. Response of non-structural components.


Associate Professor Hyonny Kim, Ph.D.—Mechanics of composite structures and materials. Failure prediction of adhesive joints. Multifunctional composite materials. Hail ice impacts. Characterization and modeling of ice material. Buckling and stability of composite structures. Nano-structured materials and modeling.


Professor John B. Kosmatka, Ph.D., P.E.—Advanced composites for aerospace, civil, and sports structures. Linear and nonlinear structural dynamics, stability, aeroelasticity, and structural health monitoring. Vibration control using embedded passive and electro-active materials.


Associate Professor Petr Krysl, Ph.D.—Computational analysis of solids and structures with finite element and element-free methods. Computer-aided geometric analysis and design. Computational biomechanics and bioacoustics.


Associate Professor Falko Kuester, Ph.D.—Tera-scale scientific visualization and virtual reality. Image-based modeling and rendering. Distributed and remote visualization.


Professor Francesco Lanza di Scalea, Ph.D.—Nondestructive evaluation. Structural health monitoring. Wave-based diagnostic systems for smart structures. Time-frequency processing. Experimental mechanics.


Professor J. Enrique Luco, Ph.D.—Earthquake engineering. Strong motion seismology. Wave propagation in solids. Dynamics. Soil-structure interaction. Foundations. Active control of seismic response of structures. Effects of topography on earthquake ground motion.


Professor Emeritus M. J. Nigel Priestley, Ph.D.—Seismic design of concrete and masonry structures. Seismic design philosophy.


Associate Professor Yu Qiao, Ph.D.—High performance infrastructural materials. Novel applications of nanoporous technology in damping and intelligent structures. Size effects in thin solid films. Energy-related materials.


Professor José I. Restrepo, Ph.D.—Seismic design and retrofit of buildings and bridges. Development of construction alternatives suited to performance-based design. Large-scale shake-table tests, and nonlinear dynamic response of buildings and structural components.


Professor and Dean Frieder Seible, Ph.D., P.E.—Bridge design. Earthquake engineering. Structural concrete and advanced composite design. Large-scale structural testing.


Adjunct Professor Maurizio Seracini, Ph.D.—Collaborative work on mapping ancient works using visualization technologies. Decay and diagnosis of materials in historical buildings. Thermographic analysis of wall structures. Restoration of historical monuments.


Professor and Vice-Chair P. Benson Shing, Ph.D.—Theoretical and experimental investigations of nonlinear behavior of concrete and masonry structures under extreme static and dynamic loads, including nonlinear finite element modeling and large-scale testing.


Associate Professor and Vice-Chair Michael D. Todd, Ph.D.—Structural health monitoring methodologies. Applied nonlinear dynamics and chaos. Structural dynamics and vibrations. Time series analysis. Fiber optic sensors for structural monitoring.


Professor Chia-Ming Uang, Ph.D.—Seismic design of steel structures. Earthquake engineering. Seismic design methodology. Large-scale testing. Seismic design of wood frame structures.


Lecturer Yael ("Lelli") Van Den Einde, Ph.D.—Performance-based earthquake engineering. Large-scale experimentation. Data management. Cyberinfrastructure. Curriculum development.


Assistant Professor Qiang Zhu, Ph.D.—Nonlinear free-surface waves, wave-body interactions. Dynamics of highly-flexible mooring systems. Computational simulation of offshore structures. Locomotion of aquatic creatures. Modeling of biopolymers.

UCSD

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附錄三 **PEER 簡介**

What is PEER?

The Pacific Earthquake Engineering Research Center (PEER) is a multi-institutional research and education center with headquarters at the University of California, Berkeley. Investigators from over 20 universities, several consulting companies, plus researchers at various State and Federal government agencies contribute to research programs focused on performance-based earthquake engineering in disciplines including structural and geotechnical engineering, geology/seismology, lifelines, transportation, risk management, and public policy.

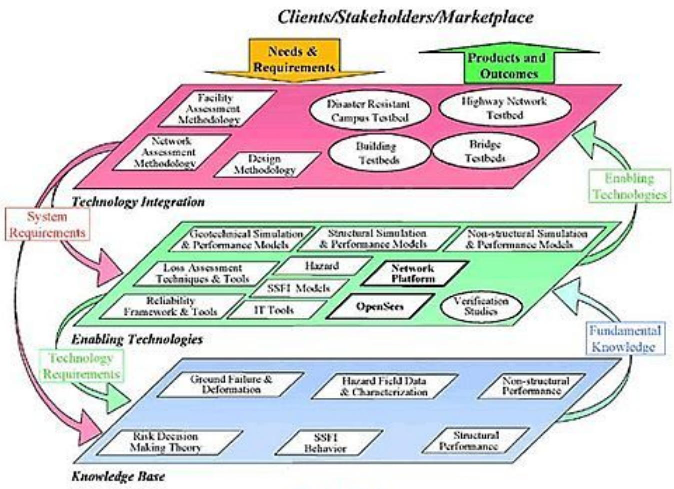
The PEER mission is to develop, validate, and disseminate performance-based seismic design technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society. PEER's research defines appropriate performance targets, and develops engineering tools and criteria that can be used by practicing professionals to achieve those targets, such as safety, cost, and post-earthquake functionality.

In addition to conducting research to develop performance-based earthquake engineering technology, PEER actively disseminates its findings to earthquake professionals who are involved in the practice of earthquake engineering, through various mechanisms including workshops, conferences and the PEER Report Series. PEER also conducts Education and Outreach programs to reach students, policy makers, and others interested in earthquake issues.

PEER was established as a consortium of nine West Coast Universities in 1996 and gained status as a National Science Foundation Engineering Research Center in 1997. PEER graduated from NSF Funding in 2008 and is now supported by federal, state, local and regional agencies together with industry partners. Despite this funding shift, PEER continues to grow and remains an active earthquake engineering research center with a wide spectrum of technical activities and projects. PEER continues to have nine Core Institutions but also actively involves researchers, educators, students, and earthquake professionals from across the US and worldwide.

Developing seismic design technologies to meet the diverse economic and safety needs of owners and society

The PEER mission is to develop and disseminate technologies to support performance-based earthquake engineering (PBEE). The approach is aimed at improving decision-making about seismic risk by making the choice of performance goals and the tradeoffs that they entail apparent to facility owners and society at large. The approach has gained worldwide attention in the past ten years with the realization that urban earthquakes in developed countries – Loma Prieta, Northridge, and Kobe – impose substantial economic and societal risks above and beyond potential loss of life and injuries. By providing quantitative tools for characterizing and managing these risks, performance-based earthquake engineering serves to address diverse economic and safety needs.



3 Plane Chart

PEER's Benefits to California

California has the greatest seismic risk exposure of any state in the country. The average annual projected losses to the building stock alone are estimated by FEMA at approximately $3.3 billion in California, or approximately 75% of all the known annualized seismic risk of the entire country. This is due to the combination of high seismicity and high concentration of population and associated businesses and industry in seismically active areas.

The PEER Center's research and technology transfer activities benefit the State by helping to systematically reduce seismic risk through the development of performance-based earthquake engineering technologies and products, the transfer of the results of the Center's research to the public and private sectors, and in the training of future students, engineers and researchers.

During the lifetime of the PEER Center the average level of seismic hazard mitigation statewide exceeded $5 billion. Even with such a large expenditure of monies into seismic hazard mitigation, much remains to be done. To help make that seismic hazard mitigation more cost effective, the PEER Center has undertaken both basic and applied research programs, incorporating a user-driven approach in which researchers, funding entities and those who implement seismic hazard mitigation work together to develop credible and useful contributions to increasing seismic safety throughout the state. The PEER Center's world-renowned research has already had a major positive impact on the utilities, transportation, and buildings fields.

Major PEER Center activities that have made a significant impact include:

- **Improvements in the safety and reliability of electricity and transportation lifelines through focused research and implementation activities.**
- **The production of new data and models for ground shaking and ground failure hazards statewide, leading to major improvements in hazard assessment now in widespread use for all types of constructed facilities**
- **Development of new procedures for assessment and design of buildings, now widely used in performance assessment and retrofitting of existing hazardous buildings as well as the design of new buildings.**

These activities have come from both the Core Program and the Lifelines Program of the PEER Center.

Specific products now in widespread use in California include:

- The PEER strong ground motion database, which has become the go-to resource for ground motions for use in seismic design of constructed facilities.
- The NGA models for ground motion attenuation, which are now the basis for seismic hazard mapping in California.
- Seismic assessment models for older hazardous concrete construction, adopted as the basis for seismic assessment standards now in widespread use to assess existing hazardous construction including hospitals, schools, and other buildings.
- New models for seismic response of liquefiable soil deposits, which assists engineers, planners, and emergency response officials assess hazards and design requirements for bridges, levees, buried pipelines, and ports, harbors, and marine oil terminals in California.


Core Institutions
University of California, Berkeley
- Lead Institution
California Institute of Technology
Stanford University
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, San Diego
University of Southern California
University of Washington


Educational Affiliates
California Polytechnic State University, San Luis Obispo
California State University, Los Angeles
California State University, Northridge
Oregon State University
San Jose State University
University of Hawaii

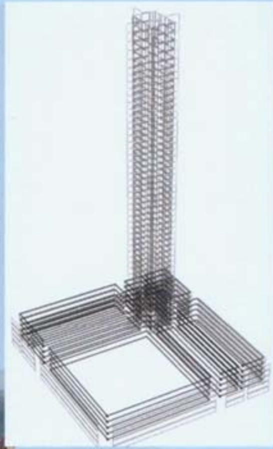

PEER Partners
Caltrans
PG&E
Martin & Associates
RMS
Risk Management Solutions
Fugro
miyamoto. Structural & Earthquake Engineering
FM Global
Exponent
JCE Structural Engineering Group, Inc.
Structural & Earthquake Engineering Consultants
Degenkolb
R&C
Rutherford & Chekene
Certus
WJE
Engineers
Architects
Materials Scientists
Wiss, Janney, Elstner Associates, Inc.
Forell/Elsesser Engineers, Inc.
Structural Engineers
GeoVera Insurance
Kleinfelder
Bright People. Right Solutions.
CDComartin,Inc
AMEC Geomatrix
Simpson Gumpertz & Heger
Engineering of Structures and Building Enclosures
EQECAT
An ABS Group Company
Geosyntec consultants
MMI Engineering
AIR
BL Schmid Consulting Structural Engineering
Earth Mechanics, Inc.
Geotechnical and Earthquake Engineering
Bechtel

PEER Projects

PEER researchers collaborate on multidisciplinary projects with the goal of developing, validating and disseminating performance-based seismic design technologies that advance the practice of earthquake engineering.

Tall Buildings Initiative

To meet the demand for new high-rise construction along the west coast of the United States, PEER is working with leading professionals from the design and regulation communities to create guidelines for the performance-based seismic design and analysis of high-rise buildings.

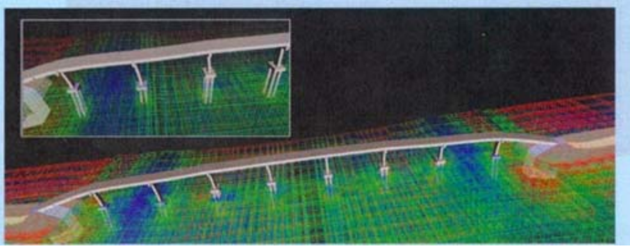


Transportation

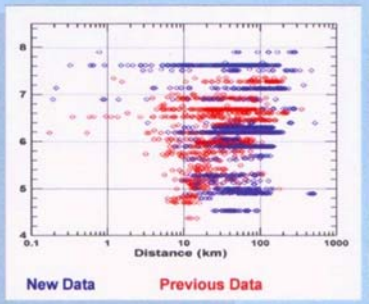
Computational, experimental and theoretical investigations by PEER reduce the impacts of earthquakes on California's transportation systems, including highways and bridges, port facilities, high speed rail, and airports. This work integrates seismological, geotechnical, structural, and socio-economical aspects.

OpenSees

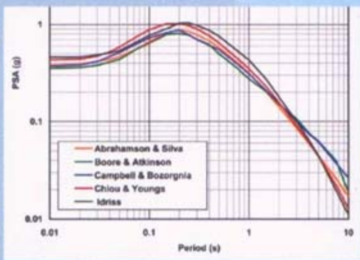
OpenSees is a robust open-source software that calculates the dynamic response of facilities to earthquake ground shaking. It has the unique capability of accurately modeling soil-foundation-structure interaction and is available free of charge to earthquake researchers and professionals.



NGA Models



Next Generation Attenuation (NGA) Models are used to estimate ground motions that can occur at any building site based on historically recorded ground motions. PEER is coordinating a comprehensive project to generate a new set of these models for the eastern United States following a successful project for the west coast of the US. The recorded ground motions have also been made into a comprehensive database for the use of design engineers.



Lifelines

PEER, in collaboration with Caltrans, PG&E, and the California Energy Commission, has initiated more than 100 lifelines research projects. These projects range from engineering characterization of earthquake ground motion, to seismic analysis of bridge structures, to performance of substation equipment and utility buildings, to emergency response efforts for lifelines after earthquakes.

NEES Grand Challenge: Nonductile Concrete

Many old concrete buildings built prior to building code requirements for ductile design have poor detailing that makes them vulnerable during earthquakes. This project is directing laboratory tests and analyses to identify the most dangerous conditions, then working with local engineers and jurisdictions to develop effective mitigation programs.

Educational Programs

PEER educational outreach includes educational seminars and workshops for practicing engineers, internships for undergraduate students, tours of research facilities, and a K-12 outreach program that teaches local elementary school students about earthquake engineering and allows them to design, build and test their own building models on a shaking table.

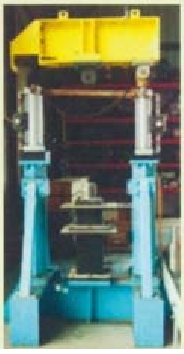
附錄四 UC Berkeley 之結構試驗設備

Shaking Table

The earthquake simulator was the first of its kind in the world. Significantly upgraded in 1996, it is a 20 ft. x 20 ft. shaking table configured to produce three translational components of motion; one vertical and two horizontal, as well as three rotational components; pitch, roll and yaw. These six degrees of freedom can be programmed to reproduce any wave forms within the capacities of force, velocity, displacement, and frequenc of the system. It may be used to subject structures weighing up to 100,000 lbs. to horizontal accelerations o up to 1.5 G. Examples of past work include testing of ba isolation systems for structures and water tanks, electric utility switches, concrete bridge columns and woodframe housin structures.

Expansion Joint Test Machine

The seismic expansion joint test machine consists of two orthogonally placed actuators that are attached to an expansion joint to provide longitudinal anc transverse excitations. The servo-hydraulic actuators have a 2540 mm (100 in) stroke and achieve loading velocity of 1092 mm/sec (43 in/sec) at 67 kN (15 kip) dynamic loading.

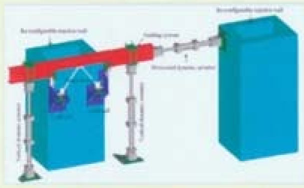


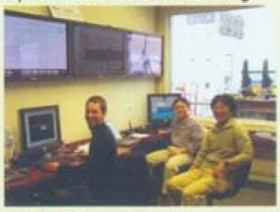
Damper Test Machine

The two damper machines consist of a reaction frame and actuator configuration that can test a wide range of damper sizes. The largest machine can deliver 900 kN (200 kip) at 0.38 m/sec (15 in/sec) during dynamic tests and a peak-to peak stroke of 24 inches.

Reconfigurable Reaction Wall & Strong Floor

There are twenty-four hollow modular reinforced concrete wall units that may be post-tensioned to the strong floor to build one or more reaction walls up to 13 m (42.5 ft) in height. The wall's maximum shear force and bending moment is 1780 kN (400 kip) and 5420 m-kN (4000 ft-kip), respectively. The structural tie-down floor has a 20 x 60 foot area that provides a completely versatile facility for testing large structural assemblies. This laboratory was designed to perform hybrid simulation testing.





4M lb Press

The 4,000,000 Pound Southwark-Emery Universal Testing Machine was built in 1932 then transported to the Richmond Field Station in 1965. This hydraulic machine is designed to permit testing in tension, compression, and bending or flexure.

MICRO LABORATORY

The micro-nees Laboratory sits adjacent to the main test area of the nees@berkeley Laboratory. Its intended use is primarily for smaller independently-run experiments although setups can easily be integrated with the larger tests involving the NEESgrid. The lab has various actuators that can be used with both NEES and non-NEES controllers. Additionally the lab has two uni-directional dynamic shakers that are primarily used for demonstrations and K-12 student outreach programs.