行政院及所屬各機關出國報告

（出國類別：其他—出席國際會議）

出席第十四屆中美水資源技術合作年會報告

服務機關：台灣省自來水公司

出國人職稱：組長

姓名：葉陳萼

出國地區：美國

出國期間：九十年八月十一日至八月十九日

報告日期：九十年十一月十四日

行政院及所屬各機關出國報告提要　　　　系統識別號：C09003546

出國報告名稱：出席第十四屆中美水資源技術合作年會報告　　　頁數 15 含附件：否

出國計畫主辦機關：經濟部水資源局(台灣省自來水公司等機關)

聯絡人/電話：邱崇照/04-22244191-276

出國人員：葉陳萼等十二人。

出國類別：其他-出席國際會議

出國期間：九十年八月十一日至八月十九日

出國地區：美國

報告日期：九十年十一月十四日

分類號/目：G4/土木工程

關鍵詞：中美水資源技術合作年會、水庫

內容摘要：

1、2001 年(第 14 屆年會)由美方主辦，我方由經濟部水資源局林副局長襟江領隊，參加單位有水利處、台灣大學、交通大學、成功大學、中華顧問、中興顧問、自來水公司及屏東水利會等共十二人。期間參訪由美方所安排之胡佛水庫、科羅拉多州流域貯蓄計畫區工程建設勘察並與其工程管理人員進行座談研討交流、十七日則在丹佛市美國墾物局舉辦第十四屆中美水資源技術合作年會，並進行中美雙方工程技術論文發表研討。

2、本次參訪對於美國得天獨厚的自然條件、優良的建壩位址、良好的集水區條件、重視水利工程建設、落實水資源管理建設及人民對水庫集水區遊憩期間之高度公德心，皆有極深刻印象。

3、水庫為台灣水資源運用上極重要之憑藉，在優良、可行的壩址不易尋覓情形下，如何延長水庫壽命便為現今水資源管理與研究最重要課題，而影響水庫壽命者為泥砂問題，故如何有效防淤、減淤，並維持水庫有效庫容，應為台灣未來需要亟思努力解決的重要工作。

4、如美國 Hoover Dam 等大型水庫，皆設有兼具歷止意義、美學藝術、工程教育及水資源保育等多重意涵之教育中心，並同時於軟体上提供專業的導覽服務。除了可增旅客遊憩景點外，並可使造訪的遊客瞭解並培養對工程建設與水資源及人類生活密切相關的認知涵養。此種理念構想，值得我方省思學習。

5、中美雙方水資源技術合作十多年來合作關係良好，並得到很好的成果，未來除了應更加強彼此的合作工作外，宜籌劃往後的合作計畫，逐年依雙方需求互相推動。

本文電子檔已上傳至出國報告資訊網

目錄

第一章、出國目的

我國於民國七十七年起與美國內政部墾務局簽訂技術合作計劃協助當時正興建中的鯉魚潭、南化及牡丹等大型水庫之設計施工等技術指導。該技術合作計劃乃透過我北美事務協調會(CCNAA)與美方在台協會(AIT)簽署合作合約，依實際之技術需要，函請美方內政部墾務局派遣相關專家協助。因皆屬水庫興建為主要而訂為「中美水壩技術合作計畫」。嗣後，為擴展水資源技術合作之需要修訂為「中美水資源技術合作計畫」。

為促進合作之實質效益及檢討合作計劃成果，乃每年訂期舉辦年會，第一屆於一九八八年由我方召集，而後此項年會輪流在中美兩地舉行。今年二００一年（第十四屆年會）適輪由美方主辦，我方出席第十二屆年會由經濟部水資源局林副局長襟江領隊，參加單位及人員有水利處陳副處長義平、國立台灣大學李教授鴻源、國立成功大學詹教授錢登、中華顧問陳工程師泉旭、中興工程顧問公司龔協理誠山、省自來水公司葉組長陳萼、屏東水利會黃主任信茗、國立交通大學楊教授錦釧、國立交通大學許研究助理教授盈松等共十二人，詳如附錄一。

我方一行人於八月十一日啟程抵美，展開由美方所排規劃的研討及工程勘察行程。首站赴世界著名大壩湖佛水庫，進行工程勘察及技術研討。延續胡佛水庫工程勘察及技術研討行程，並與胡佛水庫工程管理人員進行座談研討交流、科羅拉多州流域貯蓄計畫區（Colorado River Storage Project, CRSP）進行工程建設勘察及技術研討行程、以及進行中美雙方工程技術論文發表研討。除勘察研究中心著名之水利工

程試驗室，並將與美方研究人員進行技術研討交流。對於其工地佈置、水資源聯合運用、生態、環境保育及營運管理制度之設計周詳及先進的觀念留下深刻的印象，並可供我國水資源開發之借鏡。

本第十四屆界水資源技術合作年會安排於科羅拉多州丹佛市美國內政部墾務局大樓舉行，由我方領隊林副局長襟江及美方墾務局開墾服務中心局長 Michael J.Roluti 共同主持，除我方團員全體十二人出席外，美方水資源、地工、環境、霸工、施工、泥沙等各專業人員十七人皆出席共同討論，足見其對本合作計畫之重視，賓主計三十餘人聚集討論，並預定明年於台灣舉行第十五屆年會。

第二章、參訪行程

八月十一日至八月十二日	由台灣桃園機場搭機赴美，經洛杉磯夜底拉斯維加斯，並與美方墾物局人員會合。
八月十二日至八月十三日	與美方人員會合後，展開由美方所安排規劃的研討及工程勘察行程。首站赴世界著名大壩胡佛水庫，進行工程勘察及技術研討。
八月十三日至八月十四日	延續胡佛水庫工程勘察及技術研討行程，本日並將與胡佛水庫工程管理人員進行座談研討交流。
八月十四日至八月十五日	抵達科羅拉多州流域貯蓄計畫區進行工程建設勘察及技術研討行程。
八月十六日至八月十八日	抵達丹佛市墾物局技術研究中心。八月十六日並著手準備次日中美年會技術研討事宜。八月十七日舉辦第十四屆中美水資源技術合作年會，以及進行中美雙方工程技術論文發表研討。八月十八日除勘察研究中心著名之水利工程試驗室，並將與美方研究人員進行技術研討交流。
八月十八日至八月十九日	結束行程，八月十八日搭機返台，八月十九日返底國門。

第三章 過程

一、第十四屆中美水資源技術合作年會

(一)、會議議程

1、 地點：丹佛市美國墾務局第六十七號大樓一樓會議室

2、 時間：二００一年八月十七日（星期五）上午八十三十分。

3、 歡迎致詞：美國墾務局開墾服務中心局長 Michael J.Roluti 致詞。

4、 開幕致詞：中華民國代表團 林副局長襟江 致詞。

5、 合作計畫工作成果報告

(1)第六號合作計畫水資源開發合作成果報告：經濟部水資局林副局長襟江報告

(2)第七號合作計畫水庫淤積合作成果報告：國立交通大學楊教授錦釧、國立台灣大學李教授鴻源報告、中興工程顧問公司龔協理誠山報告、國立成功大學詹教授錢登報告

(3)美方對技術合作計畫成果報告：墾務局 Dr. Chih Ted Yang 報告

6、 專題演講

a、美墾務局楊志達博士。

b、美陸軍工兵團曾建平博士。

C、美墾務局 Dr. Blair.

7、 討論

8、 閉幕

(二)、第十四屆中美水資源技術合作年會紀要

本屆年會於八月十七日(星期五)上午八時三十分假美國丹佛市墾務局大樓會議室舉行。

1、 先由美國墾務局開墾服務中心局長 Michael J.Roluti 致歡迎詞:詳如附錄二。

2、 著我方代表團領隊林副局長襟江致開幕詞:詳如附錄三。

3、 我方計畫成果報告:

(1)第六號水資源開發合作計畫成果報告:經濟部水資源局 林副局長襟江報告。詳如附錄四。

(2)第七號水庫淤積合作計畫成果報告:

國立交通大學楊教授錦釧報告:報告主題為「Evaluation of Sino-U.S. Cooperative Program Achievements on Reservoir Siltation Technical Support, by Jinn-Chuang Yang」,此部份內容詳如附錄五。

國立台灣大學李教授鴻源報告:報告主題為「Numerical Simulations in an Alluvial Channel Network | Applications of NETSTARTS, by H.Y.Lee and H.M.Hsieh」,此部份內容詳如附錄六。

中興工程顧問公司龔協理誠山報告:報告主題為「Damage and Rehabilitation Work of Shih-Kang Dam, by Chen-Shan Kung, Wei-Pin Ni, and Yun-Jen Chiang」,此部份內容詳如附錄七。

國立成功大學詹教授錢登報告:報告主題為「Brief Report on Reservoir Sedimentation Survery in Taiwan 2000, by Pei-Hwa

Yen」，此部份內容詳如附錄八。

4、 美方對技術合作計畫成果報告：墾務局楊博士志達報告：報告主題為「Summary Report for Appendices.6 and 7 from Reclamation, by Chih Ted Yang」，此部份內容詳如附錄九。

5、 專題演講

Appendix-A-Selected Papers by Chih Ted Yang on River Morphology

Appendix-B-Selected Papers on the U.S. Army Corps of Engineers Kissimmee River Restoration Project and Floodplain Management

Appendix-C-Selected Papers on Dam Removal

(三)、 結論

1、美國內政部墾務局、經濟部水利處和經濟部水資源局同意繼續延長辦理現行中美水資源發展技術支援協議五年並開始於二００二年一月。合約雙方當事人同意修正附錄六有關技術服務中心之美國內政部墾務局內外部雇用人員工作報酬匯率。原附錄六工作範圍將增列河川復育事項。

2、美國內政部墾務局和經濟部水資源局同意延長附錄七工作五年並始於二００二年一月。

3、續延之附錄七工作內容將加強繼續 GSTARS 3.0 在水庫淤積之應用和集水區沖蝕過程方面之研究。

4、在附錄七下，五年研究將分成二階段進行。第一階段二年，將建立集水區沖蝕過程之工作範圍及方法。其餘三年將發展出一套可應用於個案研究之方法。

5、在附錄七下，第一階段研究，經濟部水資源局將選擇採用下列二方案中之一或兩個：

（1）每年提供 10,000 元美金給美國內政部墾務局楊志達博士，作為提供初步諮詢之用。

（2）每年提供 100,000 元美金給美國內政部墾務局，用於發展合理化沖蝕方法和模式，美國內政部墾務局將提供有關物理之觀念、數學和數值公式、及個案研究結果之詳細資料。

上述由台灣支付之實際經費，將依每年預算額度而定。

(原結論簽署稿詳附錄十)

二、工程觀摩訪問紀要

(一)Hoover Dam

Hoover Dam 位於 Colorado's Rocky Mountains 流域上，為舉世知名的大型拱壩。在此埧興建運轉以前，Colorado River 經常於春季或初夏時因上游集水區融雪，造成沿岸低地之洪氾災害。而於夏末或初秋時期，則因河水位過低或乾旱造成灌溉或畜牧之困難。

Hoover Dam 興建於 1931 年，最後之混凝土灌漿完成於 1935 年。Hoover Dam 無疑是興建當時規模最為龐大的拱埧。其位於內華達州拉斯維加斯附近之 Black Canyon，為國際上歷史性土木工程著名地標，亦為美國七大現代土木工程奇蹟之

一。美國羅斯福總統於 1935 年 9 月 30 日題獻 Hoover Dam，水庫發電廠於 1936 年完成，是年 10 月第一組機組開始進行運轉；而第十七組亦為最後完成之發電機組於 1961 年進行商業運轉。Hoover Dam 之水庫所在之 Lake Mead 為美國最大之人工所造成水庫湖泊，其以美國墾務先鋒 Dr. Elwood Mead 命名。Lake Mead 容量為 28.5 億畝｜英呎(acre-feet)，或蓄積近二年之平均逕流總量。

Hoover Dam 乃以美國第 31 屆總統 Herbert Hoover 命名 Hoover Dam 原亦名 Boulder Dam。因 Hoover 總統之開創性遠見，強力支持水利工程建設，並擬藉由超大型混凝土壩來控制 Colorado River，進而能消洪減災，並提供穩定可靠水資源，以利農業民生並使用南加州廣大地區擁有獨立可靠水源。緣於 Hoover 總統之貢獻，美國國會於 1947 年決定以其姓氏為水庫命名。

根據 Hoover Dam 綱領計畫「The Boulder Canyon Project Act」所擘畫該水庫之主要功能使命包括：洪災控制，Colorado River 航運管理，以利於公有地墾務及其他有益使用目的所需水資源儲蓄及運輸，水力發電等。Hoover Dam 之興建對於美國西南區域之發展有極大影響，其具體效益展現於以下各方面：

1、　灌溉

Hoover 水庫所提供灌溉水源能夠廣及一百萬英畝最富庶的美國穀物田地與五十萬英畝 Mexico 農田。這些農田主要生產各式水果、蔬菜、棉花及牧草等，每年有數

以億美元計之經濟效益。

2、 公共用水

Hoover 水庫所提供公共用水範圍包括 Las Vegas, Los Angelas, San Diego, Phoenix, Tucson 其他城市鄉鎮等地，涵蓋 Arizona, Nevada 及 California 等州，用水人口總數超過二仟萬以上。

3、 水利發電

Hoover Dam 提供低廉之水力發電供 Arizona, Nevada 及 California 等州使用，促進了本區域之蓬勃發展。Hoover Dam 能夠獨立提供每年四億 Kilowatt-hours 電力，足以供一仟三佰萬人使用所需。

4、 休息遊憩

Hoover 水庫集水區為由美國國家公園管理局所管理，並為 Lake Mead National Recreation Area 之一部分，並包括 Hoover Dam 下游之 Lake Mohave。其壯闊美麗的景觀，每年吸引九佰萬人以上之遊客，並可從事游泳、划船、釣魚及其他水上休閒活動。此外，此區之野生及原生動植物亦受到嚴格之適當保護。

(二)、Morrow Point Dam

本壩及水力發電廠興建完成於 1970 年 12 月，Morrow Point Dam 在 USBR 之水壩興建經驗中有極特殊之特色，包括：

1、 為美國第一座大型雙曲(double-curvature)薄拱(thin-arch)混凝土壩。雙曲型設計係指壩拱除由左至右之水平拱型外，及由

底部至頂部之垂直拱型。本壩高 469 呎、724 呎長，底部厚 52 呎，頂部厚 12 呎，總計有 365,000 立方碼(cubic yards)混凝土。

2、 壩具有獨特之自由跌水溢洪道，其由四座 15 平方呎閘門所構成。當水庫洩洪時將有高 350 呎之巨大射流，投射至 60 呎深之靜水池。

3、 本壩之發電廠設置於地下岩壁中，電廠寬 50 呎、長 225 呎、頂高 65 呎。本壩具有二座發電機組，總額定發電量為 156,000 Kilowatts.

Morrow Point 水庫總容量為 117,000 acre-feet，水庫面積涵蓋 817 英畝，沿庫區長 24 哩，其下游則興建有 Blue Mesa Dam。

(三)、Blue Mesa Dam

本壩興建完成於 1965 年 10 月，壩體是由總量達 3,085,000 立方碼(cubic yards)之土石所構築之楔型壩，壩高 342 呎。本水庫容量 940,800 畝-呎(acre-feet)，庫區面積 14.3 平方哩、周長 96 哩，當其滿水位時為 Colorado 州最大湖區。

本水庫提供灌溉用水、水力發電及遊憩休閒等多功能目標。本水庫水力發電有兩套機組，總額定發電量為 87,000 Kilowatts。

第四章、心得

一、 本次參訪對於美國得天獨厚的自然資源條件、優良的建壩位址、良好的集水區條件、重視水利工程建設、落實水資源管理建設及人民對水庫集水區遊憩期間之高度公德心，皆有極深刻印象。相較於台灣因河短湍急、地質條件不佳、水保工作欠佳、水庫泥砂淤積嚴重等特性，使得台灣水資源建設與管理工作更加困難。

二、 國 Hoover Dam 等大型水庫，皆設有兼具歷史意義、美學藝術、工程教育及水資源保育等多重意涵之教育中心，並同時於軟硬體上提供專業的導覽服務。除了可增旅客遊憩景點外，並可使造訪的遊客瞭解並培養對工程建設與水資源及人類生活密切相關的認知涵養。此種理念構想，值得我方省思學習。

三、 美國為一地廣人稀之國家，國民皆極喜愛戶外休閒，亦有許多人熱衷野外活動。此外，美國亦為一極具生態保護理念之國家。而事實上，美國之水庫建設極多，亦普遍為民眾所認同。然人類原本就需與自然共存，故適度之開發建設是必需的。故許多水庫庫區雖因部分人為改變，但其整體的貢獻仍是顯著正面的。故如何讓一般民眾對於水庫開發建設有正確的認識，並對於生態保育的理念與作法有較為切合的省思認知，應是國人所必需共同努力的。

第五章、建議

一、水庫為台灣水資源運用上最根本重要的憑藉，在優良、可行的壩址不易尋覓情形下，如何延長水庫壽命便為現

今水庫資源管理與研究最重要課題。而影響水庫壽命者為泥砂問題，故如何有效防淤、減淤，並維持水庫有效庫容，應為台灣未來需要亟思努力解決的重要工作。

二、中美雙方水資源技術合作十多年來合作關係良好，並得到很好的成果，未來除了應更加強彼此的合作工作外，宜籌劃往後的合作計畫，逐年依雙方需求互相推動。

附錄一、本屆合作年會出席人員一覽

附錄二、本屆合作年會美方歡迎致辭

附錄三、本屆合作年會我方開幕致辭

附錄四、第六號水資源開發合作計畫成果報告：經濟部水資源局林副局長襟江

附錄五、Evaluation of Sino-U.S. Cooperative Program Achievements on Reservoir Siltation Technical Support, by Jinn-Chuang Yang

附錄六、Numerical Simulations in an Alluvial Channel Network—Applications of NETSTARTS, by H.Y.Lee and H.M.Hsieh

附錄七、Damage and Rehabilitation Work of Shih-Kang Dam, by Chen-Shan Kung, Wei-Pin Ni, and Yun-Jen Chiang

附錄八、Brief Report on Reservoir Sedimentation Survery in Taiwan 2000, by Pei-Hwa Yen

附錄九、Summary Report for Appendices.6 and 7 from Reclamation, by Chih Ted Yang

附錄十、本屆合作年會結論

2001 AIT-TECRO Water Resource Program
Annual Review Meeting
List of Participants

I. Delegation from Taiwan

Name	Organization	Position
Jing-Join Lin	Water Resources Bureau Ministry of Economic Affairs	Deputy Director and Head of Delegation
Yi-Ping Chen	Water Conservancy Agency Ministry of Economic Affairs	Deputy Director
Jinn-Chuang Yang	Department of Civil Engineering National Chiao-Tung University	Professor
Yin-Sung Hsu	Natural Hazard Mitigation Research Center, National Chioa Tung Univ.	Research Assistant Profes
Hong-Yuan Lee	Department of Civil Engineering National Taiwan University	Professor
Chyan-Deng Jan	Dept. of Hydraulic and Ocean Eng. National Cheng Kung University	Professor
Chuan-Hsu Chen	Water & Environmental Department China Engineering Consultants, Inc.	Engineer
Chen-E Yeh	Planning Division Taiwan Water Supply Company	Branch Chief
Hsin-Ming Huang	Data Processing Division Pin-Tung Irrigation Association	Branch Chief
Chen-Shan Kung	Hydraulic Engineering Department SINOTECH Engineering Consultants, Ltd.	Manager
Lain-San Lin	Water Conservancy Agency Ministry of Economic Affairs	Deputy Chief Engineer
Meng-Hsiung Cheng	Institute of Planning and Hydraulic Research, Water Conservancy Agency, Ministry of Economic Affairs	Engineer

ureau of Reclamation Delegation

Name	Organization	Position
ael J. Roluti	Technical Service Center	Director and Head of Delegation
s Pierce	Water Resources Services Division Technical Service Center	Chief
ırd Throner	Geotechnical Services Division, Technical Service Center	Chief
Ted Yang	Sedimentation & River Hydraulics Group, Technical Service Center	Manager and Liaison Officer
ıas Mitchell	Technical Service Center	Client Liaison
:t Hickox	Commissioner's Office	International Specialist
ıce Duster	Technical Service Center	Technical Review Team Leader
Tseng	Hydraulics & Hydrology Branch U.S. Army Corps of Engineers	Chief
Chat	Technical Service Center	Construction Engineer
as Hepler	Technical Service Center	Hydraulic Structural Engr.
McKeown	Consultant	Engineering Geologist
Aberle	Consultant	Grouting Specialist
a Principe	Technical Service Center	International Team Leader
d Ferrari	Technical Service Center	Hydraulic Engineer
sco Simões	Technical Service Center	Hydraulic Engineer
Greimann	Technical Service Center	Hydraulic Engineer
Young	Technical Service Center	Hydraulic Engineer

Welcoming Address
2001 AIT-TECO Water Resources Program — Annual Review Meeting

Michael J. Roluti, Director
Technical Service Center — U.S. Bureau of Reclamation

The U.S. Bureau of Reclamation is honored to host the Fourteenth Annual Review Meeting of the American Institute in Taiwan (AIT) – Taipei Economic and Cultural Office (TECO) Water Resources Program. I would like to extend my sincere welcome, on behalf of the Bureau of Reclamation, to all of the Taiwan delegates attending this annual meeting.

The Water Resources Program began in 1987 with the signing of an Agreement which allowed the U.S. Bureau of Reclamation (Reclamation) to provide technical assistance to Taiwan in dam design and construction. Since the Agreement began, four major new water resources projects, Liyutan Dam, Nan Hua Dam, Mutan Dam, and Chi Chi Common Diversion Weir, have been completed. These projects are providing much needed water supply and other benefits to Taiwan. The enlargement of another water project, Hsin Shan Reservoir, has also been completed, and plans for several other water resources projects are currently being developed. The planned projects are vital to meet future water supply needs in Taiwan. I am sure that Taiwan□s water resources agencies are very proud of their accomplishments. Reclamation is equally proud to have played a role in providing technical assistance for the successful completion of these projects.

Since 1987, the Agreement has been expanded from technical assistance in dam design and construction, to water resources management and the many issues associated with reservoir sedimentation. Reclamation is continuing to provide technical assistance for the design and construction of the Pao Shan II Reservoir and Hu Shan Reservoir Projects under Appendix 6 to the Agreement. Our sedimentation specialists, in cooperation with Taiwan□s engineers and scientists, are completing the final year□s work for the Cooperative Sedimentation Studies according to Appendix 7. The Bureau of Reclamation is fortunate to have the opportunity to share in Taiwan□s major achievements in the successful development and management of valuable water resources. We look forward to continuing the technical assistance on developing and managing water resources, and the completion of the sedimentation studies.

The future direction of the AIT-TECO Water Resources Program will likely change to include an increased emphasis on developing effective and innovative methods for managing existing water resources, rather than constructing new projects, to meet the many competing demands for water supply. Reclamation, and other water resources agencies in the United States, have experienced similar changes with the dramatic decrease in construction of new water resources projects. Reclamation□s primary water resources programs currently include repair, rehabilitation, and upgrading of existing facilities to assure public safety, and the management of existing water resources to meet various water supply needs. Assuring the safety of existing facilities through an effective Safety of Dams program is extremely important to Taiwan and to Reclamation. Additionally, effective management of existing water resources is, and will continue to be, necessary and important in both Taiwan and the United States, to assure adequate future water supplies and achieve sustainable use of available resources. The technical assistance program under Appendix 6 and the cooperative sedimentation studies under Appendix 7 to the Agreement provide an excellent means of sharing our expertise and experiences, and exchanging valuable information on current water resources development and management practices. We look forward to the continuation of this very successful AIT-TECO Water Resources Program, and will continue to support the program, as requested by the Water Conservancy Agency and the Water Resources Bureau of the Ministry of Economic Affairs.

Thank you for the opportunity to host the Fourteenth Annual Review Meeting. I hope the Taiwan delegation has enjoyed this visit to the United States, and that your visits to Reclamation water projects earlier this week were informative. If there is anything more we can do during your stay, please let us know. Again, welcome to Denver, Colorado, and to the Bureau of Reclamation facilities. We look forward to a productive and successful annual review meeting.

Meritorious Keynote for the Opening Ceremony of the Annual Sino-American Water Resources Technical Cooperation Symposium, 2001

Jin-Shan Huang, Director
Water Resources Bureau and Water Conservancy Agency
Ministry of Economic Affairs

Distinguished VIPs, ladies and gentlemen,

It is both an honor and a great pleasure to be attending the Annual Sino-American Water Resources Technical Cooperation Symposium, 2001. I would like to extend a warm welcome on behalf of the Water Resources Bureau under the Ministry of Economic Affairs, and to thank you for your enthusiasm and support.

The 21st century is shaping up to be a century dominated by the quest for water resources. More specifically, the surging world population and rapid industrial and commercial development worldwide will only aggravate the demand on our existing water resources. Soon, the world will face a crisis of surging demand for water resources.

The options for developing and utilizing water resources in the Taiwan region are limited by the region's geology. Thus far, the development effort has predominantly relied on building dams, which number more than 60 altogether, with a total capacity exceeding 2.84 billion metric meters. However, dam building is a time-consuming process, and the construction of additional dams is now stymied by several factors: the scarcity of good sites, the increased development cost, difficulties in land acquisition, and the environmental impacts associated with a dam-building project.

Bound by a harsh terrain and limited options for developing new water supplies, our efforts to fully utilize Taiwan's limited water resources have focused on the question of how best to maintain the capacity of all existing dams. We have found this to be a crucial topic that cannot be overlooked. Frequent soil erosion, arisen from a less compact geology, enhances the flow of silt into Taiwan's reservoirs and thereby shortens the operational lifetime of those reservoirs. Because of this, part of the central mission at the Water Resources Bureau under the Ministry of Economic Affairs is to improve both irrigation and conservation in the collecting areas upstream from all water-holding dams. This effort is combined with other preventive strategies, including silt removal at reservoirs and water quality improvements. Aware of the silting problem at water-holding dams across Taiwan, we at the bureau are actively forming technical pacts with renowned foreign research institutions, and we have a series of research projects underway, intended to resolve the reservoir silting problem.

The administration is very grateful and indebted to the U.S. Department of Interior's Bureau of Reclamation for its critically acclaimed water resources utilization and management know-how and for the generous recommendations and contributions that its technical team has afforded Taiwan to improve in this area. This annual gala event presents an optimal venue for the exchange of valuable technical data and essential know-how between the Bureau of Reclamation and Taiwan's Bureau of Water Resources Management. The knowledge thus acquired can help us greatly enhance dam siltation processing techniques and attain the objective of sustainable dam management.

Last but not the least, more valuable is the deep-rooted camaraderie and friendship that binds all of us together. May I once again extend our heartfelt appreciation for the generosity of the U.S. Department of Interior's Bureau of Reclamation, and hope that our close-knit cooperation may bring forth many fruitful results for the future to come. Thank you all for your participation and contributions.

The Fourteenth AIT-TECRO Water Resources Program
Annual Review Meeting
Summary Report for Appendix 6

Dr. Yen-Lang Lin, Liaison Officer
Water Conservancy Agency, Ministry of Economic Affairs
(WCA, MOEA)

Mr. Chairman, ladies and gentlemen,

For the fourteenth AIT-TECRO Water Resources Program in 2001 in the United States, the Deputy Commissioner, Mr. Chen, represents the Water Conservancy Agency, MOEA, and he will summarize the annual progress report for the AIT-TECRO Water Resources Program of the past years. He will also discuss the possibility of technical assistance from the United States.

At last year's annual review meeting, the Water Conservancy Agency announced its intention to invite three technical specialists, including Mr. Clarence Duster, from the U.S. Bureau of Reclamation to Taiwan to offer assistance. With the help from the Liaison Officer, Dr. Chih-Ted Yang, the U.S. Bureau of Reclamation sent Mr. Clarence Duster, Mr. Mark McKeown, and Mr. Peter Aberle to Taiwan in June of 2001 to provide technical guidance for the Paoshan II Dam project. Their hard work in Taiwan was greatly appreciated. The preliminary reports of the Paoshan II Dam project and Hushan Dam project were submitted before they returned to the U.S. The final report of the Paoshan II Dam project was sent to the Water Conservancy Agency at the end of July. Following the plan proposed this April, we will invite four specialists in the fields of grouting, geology, hydraulic structure, and construction from the U.S. Bureau of Reclamation, to give us technical guidance for the Paoshan II Dam, Hushan Dam, Chihmin Dam, and Malong Dam.

In 2002, the technical assistance which the Water Conservancy Agency will need from the U.S. Bureau of Reclamation includes the following:

1. It is planned that the Paoshan II Dam project will be in the process of dam foundation construction and body filling in April or May of 2002. We would like to invite the U.S. specialists to Taiwan to give construction direction for about 1 month.
2. It is planned that the basic design of the Hushan Dam is to be completed in the latter half of 2002. We would like to have a U.S. specialist come to Taiwan to help review the project report.
3. Due to shrinkage of the government budget, the number of civil service workers we are able to send abroad is restricted. In 2002 we can only send one person to attend the training program on Dam Safety, Maintenance, and Operation, which is organized by the U.S. Bureau of Reclamation. Therefore, we will try the approach of inviting the U.S. specialists to Taiwan to give training courses.

Again, as Liaison Officer, I would like to express my appreciation and many thanks to Dr. Chih-Ted Yang for his cooperation and assistance. Also, thanks are due to Mr. Clarence Duster, Mr. Mark McKeown, and Mr. Peter Aberle. Their help in 2001 is much appreciated.

Evaluation of Sino-U.S. Cooperative Program Achievements on Reservoir Siltation Technical Support

J. C. Yang
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National Chiao Tung University, Hsinchu, Taiwan, Republic of China

INTRODUCTION

The Water Resources Bureau of the Ministry of Economic Affairs (WRB, MOEA) has, in the past ten years, engaged in research and development of reservoir siltation control. It has also conducted the "Sino-U.S. Cooperative Program on Reservoir Siltation Technical Support" in collaboration with the U.S. Bureau of Reclamation to preserve the reservoir storage capacities for sustainable use of water resources in Taiwan. This study evaluates the achievements of the Co-op Program for technical suitability and practical applications to reservoir siltation control in Taiwan.

RESERVOIR SILTATION CONTROL IN TAIWAN

In Taiwan, rainfall varies greatly with the season and with location on the island. As a consequence, development and utilization of water resources are difficult. Reservoirs are important structures for water resources utilization. Siltation in reservoirs must be controlled to preserve storage capacity and allow sustainable use. According to data from the WRB, siltation in reservoirs in Taiwan has long been a problem and has taken up to 20 percent of the original design storage capacity of reservoirs. Ever worsening water shortages would be relieved if the reservoir siltation problem is solved.

Comparisons of annual surface soil loss with that in other countries would illustrate the severity of the problem in Taiwan. For instance, the average annual soil loss in the watershed of Tseng-Wen Reservoir in southern Taiwan approximates 8.8 mm; whereas the average annual soil loss in the 48 reservoir watersheds under the Tennessee Valley Authorities (TVA) in the U.S. is merely 0.25 mm. The Yellow River in China is famous for the soil loss in its watershed; its sediment concentration reaches up to 37.6 kg/m^3.

Even so, its average annual soil loss in the watershed is less than 7 mm. Surface soil loss in Taiwan is indeed amazing.

Causes of Reservoir Siltation in Taiwan

Taiwan is one of the most problematic regions in the world with respect to serious reservoir siltation. The causes of serious reservoir siltation in Taiwan are as follows:

1. The geologic formation is relatively young and its loose and soft texture is susceptible to weathering and erosion.
2. Frequent human activities and heavy land use in the reservoir watershed accelerate surface erosion.
3. Traditional design of overflow spillway allows the discharge of the upper portion of water in the reservoir that has a relatively low sediment concentration and traps most sediments in the lower portion to remain in the reservoir exacerbating siltation.

Soil lost due to surface erosion in the watershed is trapped in the reservoir after dam erection. Since the topography is mostly steep, the storage capacity of the reservoir is relatively limited, and it is impractical to provide adequate dead storage capacity for reservoir siltation in design. Consequently, the problem of reservoir siltation is critical to resource management.

Taiwan Experiences in Reservoir Desilting

Both mechanical and hydraulic desilting operations have been implemented in reservoirs for siltation control in Taiwan.

1. *Mechanical desilting*

Mechanical excavation was used in desiting operations for the Pai-Ho, Ta-Pu, Ming-Te, Te-Yuan-Pi, and Shih-Kang reservoirs. Unfortunately, the disposal of huge volumes of excavated materials becomes another problem as suitable dump sites are scarce.

2. Hydraulic desilting

Hydraulic desilting include flood flushing, drawdown sluicing, flow-through reservoir flushing, and density-current discharging. At proper times and under hydraulically favorable conditions, reservoir outlet structures may be kept open to discharge sediment-laden water. This practice removes reservoir sediments and releases reservoir inflow carrying sediments. Hydraulic desilting operations were conducted for Wu-Chieh Dam, Tien-Lun Dam, His-Pang Dam, Chien-Shan-Pi Reservoir, and Ta-Pu Reservoir to remove reservoir sediments. Nevertheless, the hydraulic desilting operations could remove sediments only down to the reservoir outlet structure and recovered little storage capacity. In addition, sediment-laden water discharge could cause channel aggradation immediately downstream of the reservoir.

GSTARS 2.0 SIMULATION OF SCOUR AND DEPOSITION OF TA-PU RESERVOIR

Input data for GSTARS 2.0 model simulation

Two case studies were performed for the scour and deposition simulation of Ta-Pu Reservoir. Case I simulates the scour and deposition of the reservoir during the period from 1987 to 1990, and Case II simulates from 1997 to 1999. Results are shown in Figures1 and 2. Additionally, the HEC-6 model was also employed to simulate both cases for comparison purposes. The required input data are as follows:

1. Cross-sectional data.—Field survey data of the cross sections of Ta-Pu Reservoir gathered in 1987 were used in Case I, and 1997 field survey data were used in Case II.

2. Conditions for hydraulic computations.—Ten-day discharges measured from 1987 to 1990 and from 1997 to 1999 were used as input discharge hydrographs for Case I and Case II, respectively. A stage-discharge rating curve was used to determine the downstream water surface elevation as the boundary.

3. Conditions for sediment transport computations.—The required input for sediment transport computations were the sediment transport capacity-discharge rating curve, the sediment inflow at the upstream end, and the grain-size distribution of the bed materials.

4. Manning's n *value.*—A Manning's *n* value of 0.035 was used for the channel roughness based on the study reports by the Miao-Li Irrigation Association (1986) and the Water Conservancy Agency of the Ministry of Economic Affairs (1999).

5. Formulae for sediment transport capacity.—Yang's sediment transport equations (Yang's 1973 sand with 1984 gravel formulae) were used for non-cohesive sediment transport capacity. Built-in formulae in the model were used for cohesive sediments transport rate based on the study report, "Operational Techniques in Siltation Control and Hydraulic Model Setup, I" by WRB, MOEA(1997).

6. Number of stream tubes.—A total of five stream tubes were assumed in the simulation. Interestingly, the simulated results between one stream tube and five stream tubes are not significantly different.

Results of Simulation

1. Results of the scour and deposition simulation of Ta-Pu Reservoir (Figures 1 and 2) indicate that the GSTARS 2.0 simulated results agree better with the field survey data than the HEC-6 simulated results.

2. Simulations should theoretically represent the real world more closely as the number of stream tubes increases. In this study, however, no significant differences in the simulated results were found with different numbers of stream tubes assumed. This could be because the cross-sectional geometry does not vary greatly from section to section.

3. Approximately 4 km upstream of the dam site at a river bend, the simulated results deviate significantly from the field survey data. This may result from the fact that GSTARS 2.0 model does not take bend effects into considerations.

4. The simulated results from the Case II study near the dam site deviate

significantly from the field survey data as result of reservoir flushing operations for desilting performed from 1997 to 1999.

PRELIMINARY EVALUATION OF GSTARS 2.1 MODEL

The GSTARS 2.0 model is considered a quasi two-dimensional river scour and deposition model that applies the stream tube concept and does not consider secondary flows resulting from river bends, lateral inflows, or density current phenomenon. The GSTARS 2.1 version, a revision of the 2.0 version, includes lateral inflows in modeling computations. Computational results for test runs using GSTARS 2.0 and GSTARS 2.1, respectively, are shown in Figure 3. It is noted that the simulated results using GSTARS 2.1 agree better with the analytical solutions than the simulated results using GSTARS 2.0.

The GSTARS 3.0 version, an improvement over the GSTARS 2 series, is currently under development. This revision will also take into consideration river bends, lateral inflows and density currents under stable condition. This new version will include the sediment transport between adjacent stream tubes and is suitable for sediment transport modeling in reservoirs.

PRELIMINARY RESULTS OF AH-KONG-TIEN RESERVOIR SIMULATION USING THE GSTARS 2.1 MODEL

Simulations of the scour and deposition of Ah-Kong-Tien Reservoir using GSTARS 2.1 model were conducted for two flow conditions; a 5-year flood and 50-year flood. Conditions after modification of the existing morning glory spillway were assumed in the simulation. The results are shown in Tables 2 and 3 along with the laboratory model testing results for comparison. The tables show that the simulated values are approximately 10 to 15 times lower than the laboratory testing results. The reasons for this drastic deviation could be that the grain sizes of the incoming sediments are very fine and the that GSTARS 2.1 model does not account for the density current phenomenon.

Although the deviations in quantity are on the order of 10 to 15 times, it is noted that the trend in variation from section to section is fairly consistent between the simulated results and the laboratory testing results.

CONCLUDING REMARKS

In Taiwan, rainfall varies greatly with the season and with location on the island. As a consequence, development and utilization of water resources are difficult. Reservoirs are important structures for water resources utilization. Siltation in reservoirs must be controlled to preserve storage capacity and allow sustainable use. According to data from the WRB, siltation in reservoirs in Taiwan has long been a problem and has taken up to 20 percent of the original design storage capacity of reservoirs. Ever worsening water shortages would be relieved if the reservoir siltation problem is solved.

Reservoirs siltation is closely related to surface erosion in the watershed. The severe reservoirs siltation problems in Taiwan may be attributed to unfavorable geologic formations, which are susceptible to erosion, and to excessive land use, which hampers surface detention potentials. To mitigate the reservoir siltation problems, appropriate siltation control and desilting operations are important.

Other than reservoir siltation control, desilting operations are also effective for sustainable use of reservoirs. Mechanical and hydraulic desilting operations are commonly used in reservoirs in Taiwan. Mechanical desilting uses equipment to remove sediments deposited in reservoirs. Hydraulic desilting utilizes water control structures and water flows to flush reservoir sediments and discharge them downstream. Effective desilting methods vary with the characteristics and features of reservoirs. Selection of suitable desilting methods should consider both the characteristics of structures and economic factors.

This study investigates the ability to use numerical modeling techniques to simulate and investigate the sediment transport phenomenon in the reservoir. It also assists in development of GSTARS 3.0 model, a co-op program between the WRB, MOEA, and U.S. Bureau of Reclamation. Initial work includes testing the suitability of the GSTARS 2.0 model for reservoir sedimentation in Taiwan by first applying this model to Ta-Pu Reservoir.

Two case studies were conducted using the GSTARS 2.0 model. Case I simulates the scour and deposition of the streambed upstream of Ta-Pu Reservoir from 1987 to 1990, and Case II simulates from 1997 to 1999. Simulated results of Case I and Case II are compared with both HEC-6 simulated results and field survey data of 1990 and 1999. The comparisons indicate that GSTARS 2.0 simulated results agree better with the field survey data than do the HEC-6 simulated results, which appear to over estimate bed deposition depths at most cross sections. It seems that the GSTARS 2.0 model performs better than the HEC-6 model in simulating Ta-Pu Reservoir.

The simulation streambed elevations agree fairly well with the field survey data except at the bends, where significant deviations are noted. This may be explained by the fact that the GSTARS 2.0 model does account for bend effects in computations.

The GSTARS 2.0 version does not consider river bends, lateral inflows, and density currents. The revised version, GSTARS 2.1, has added the capability of modeling lateral inflows. The GSTARS 3.0 version is now under development and will be mainly for reservoir sedimentation modeling. It will also include modeling capability for river bends, lateral inflows and density currents.

Table 1. Summary of reservoir desilting operations in Taiwan

Name of Reservoir	Fiscal Year	Method of desilting	Sediment Volume Removed (m^3)	Total Cost (NT $)	Unit Cost (NT $/$m^3$)
Pai-Ho	1991	Hydraulic Dredging	35,000	6,000,000	171.4
	1991	Mechanical Excavation	40,000	5,000,000	125.0
			260,000	42,000,000	161.5
	1992	Mechanical Excavation	212,000	29,960,000	141.3
	1992	Hydraulic Dredging	42,000	1,540,000	36.7
	1993	Hydraulic Dredging	8,000	880,000	110.0
	1994	Mechanical Excavation	283,200	32,000,000	112.8
Ta-Pu	–	Flow-Thru Reservoir Flushing	200,000	150,000	0.75
	1993-1994	Mechanical Excavation	638,000	34,000,000	53.29
Ming-Te	1993-1994	Mechanical Excavation	679,250	46,300,000	68.16
Te-Yuan-Pi	1991	Mechanical Excavation	73,124	23,200,000	317
	1992	Mechanical Excavation	58,695	16,512,000	281
	1994	Mechanical Excavation	32,200	3,880,000	120
Shih-Kang	1984-1993	Mechanical Excavation	170,590	Contractor sold excavated materials as construction aggregetes	104
		Mechanical Dredging	146,332		
		Hydraulic Dredging	235,546		
Shih-Men	1985-1992	Hydraulic Dredging	2,808,000	–	–
	1993	Hydraulic Dredging	300,000	81,229,000	271
Chien-Shan-Pi	1967	Pumping Discharging	5,237	44,877	8.57
	1968	Pumping Discharging	3,975	54,314	13.66
	1969	Pumping Discharging	30,394	89,091	2.93
		Rainstorm Discharging	175,111		
	1971	Pumping Discharging	5,957		
		Rainstorm Discharging	251,635		
	1973	Pumping Discharging	16,457		
		Pumping Discharging	287,515		
	1985	Mechanical Excavation	4,500		
		Rainstorm Discharging	178,990		

Note: 1. Pumping Discharging and Rainstorm Discharging operated under empty reservoir condition.
2. Data from "Planning on Reservoir Siltation Control", WRB, MOEA, 1996.

Table 2. Comparison of sediment deposition between hydraulic model testing and numerical model simulation for 5-year flood

Segment Location	Amount of Sediment Deposition (m^3)	
	Hydraulic Model Testing	Numerical Model Simulation
Inflow box of Cho-Shui Creek	290	
Cross section 35–36	90	
Cross section 34–35	136.7	8.53805
Cross section 33–34	116	17.062
Cross section 32–33	95.2	15.3275
Cross section 31–32	94.4	8.4922
Cross section 30–31	60.6	5.7889
Cross section 29–30	65.3	6.0714
Cross section 28–29	40.6	6.30895
Cross section 27–28	42.3	6.82825
Cross section 26–27	42.6	6.9017
Cross section 25–26	73.6	7.16235
Cross section 24–25	70.4	7.0038
Cross section 23–24	68.5	5.7722
Cross section 22–23	65.3	7.62335
Cross section 21–22	217.4	9.9973
Cross section 20–21	163.2	13.0005
Cross section 19–20	201.3	15.935
Cross section 18–19	390	17.3455
Cross section 17–18	326	17.2175
Cross section 16–17	245	15.9885
Cross section 15–16	444.9	11.58855
Cross section 14–15	242	4.9084
Cross section 13–14	60	2.39755
Cross section 13–Right Bank	22	
Inflow box of Wang-Lai Creek	21	
Total Sediment Deposition	3,373.3	217.2595
Total Amount of Incoming Sand	3,797.7	3,797.7
Trapping Rate	88.82%	5.72%

Table 3. Comparison of sediment deposition between hydraulic model testing and numerical model simulation for 10-year flood

Segment Location	Amount of Sediment Deposition	
	Hydraulic Model Testing	Numerical Model Simulation
Inflow box of Cho-Shui Creek	259	
Cross section 35–36	59.4	
Cross section 34–35	91.2	8.72095
Cross section 33–34	111.8	17.6955
Cross section 32–33	92	16.2095
Cross section 31–32	122.8	9.19125
Cross section 30–31	79.4	6.35385
Cross section 29–30	82.8	6.6983
Cross section 28–29	45	6.99445
Cross section 27–28	46.9	7.66495
Cross section 26–27	56.2	7.82375
Cross section 25–26	81.4	8.19245
Cross section 24–25	85.8	8.13745
Cross section 23–24	89	6.86875
Cross section 22–23	87	9.0047
Cross section 21–22	280.2	11.8575
Cross section 20–21	201	16.7555
Cross section 19–20	259	21.092
Cross section 18–19	480	21.868
Cross section 17–18	339.2	21.232
Cross section 16–17	324.7	20.1825
Cross section 15–16	634.3	14.8275
Cross section 14–15	282	6.3566
Cross section 13–14	92.5	3.30365
Cross section 13–Right Bank	45.6	
Inflow box of Wang-Lai Creek	78	
Total Sediment Deposition	4,069.2	257.03
Total Amount of Incoming Sand	6,611.8	6,611.8
Trapping Rate	61.54%	3.9%

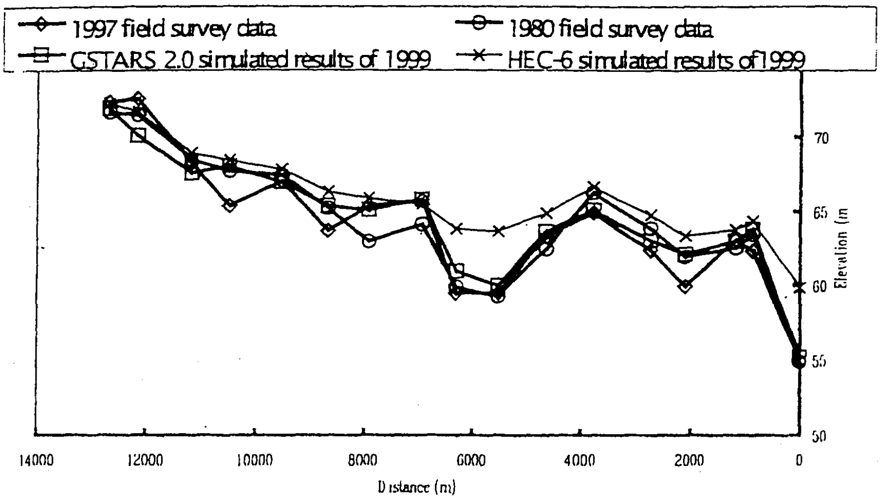

Figure 1. Simulated results of streambed elevation—Case I study.

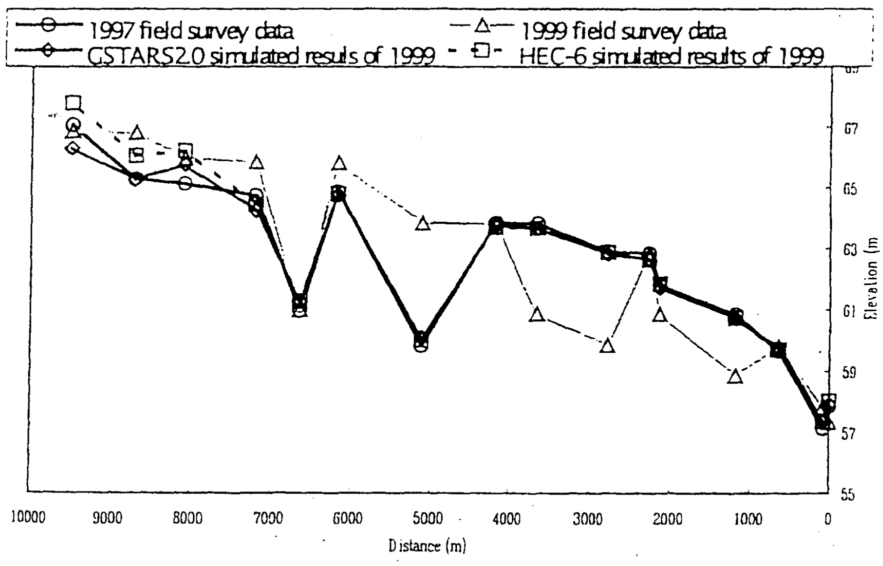

Figure 2. Simulated results of streambed elevation—Case II study.

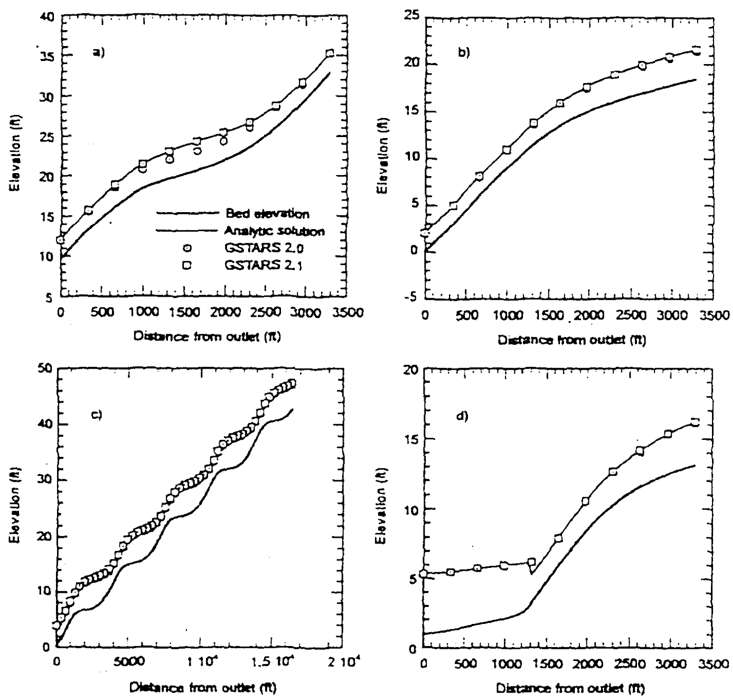

Figure 3. Results of the computation using GSTARS 2.0 and a newly revised version (denoted as GSTARS 2.1) a.) test problem #1; b) test problem # 2; c) test problem # 3; d) test problem # 4. The markers also indicate the location of the cross sections used in the computation.

Numerical Simulations in an Alluvial Channel Network — Applications of NETSTARS

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ABSTRACT

A numerical model, which is capable of simulating scouring and deposition behaviors in a channel network, is developed in this study. The model treats suspended load and bed load separately, and hence is able to simulate the depositional behavior of the suspended sediment under a nonequilibrium process. The model solves the de Saint Venant equation, and thus can be applied to unsteady flow conditions. An internal boundary condition based on the sediment transport capacity was proposed to distribute the incoming sediment load into the downstream links. The application of this model to the Tanhsui River system in Taiwan gave very convincing results.

KEYWORDS: Channel Network, Scour and Deposition , Alluvial Channel Simulation

INTRODUCTION

During the past decade, several numerical models have been developed. A comprehensi' literature survey has been conducted by the authors in their previous paper [6], and will not be repeated herein. A new model, named NETSTARS, is developed in this article to simulate the channel bed evolutions of a channel network. It treats the suspended load and bed load separately, and hence is able to simulate the depositional behaviors of the suspended sediment under a nonequilibrium process. An internal boundary condition based on the sediment transport capacity was proposed to distribute the incoming sediment load into the downstream links. The model is applied to simulate the bed evolution of the Tanhsui River system, which is an estuarine channel network to demonstrate its engineering applicability.

THEORETICAL BASIS AND GOVERNING EQUATIONS

The NETSTARS model is an uncoupled sediment routing model. It consists of two major parts, namely hydraulic routing and sediment routing. Suspended load and bed load are treated separately in sediment routing. A network algorithm was proposed to resolve the nodal point problem. A node is assumed to be a virtual section that could not accumulate water and sediment, i.e. no scour and no deposition. A nodal continuity equation was proposed in this paper. Double sweep method is applied to solve the discharges and the water stages at those nodes. The allocation of the suspended load at the node is assumed to be proportional to the allocations of the flow discharges, and the net flux of the suspended sediment due to longitudinal dispersion is assumed to be zero at a nodal point.

The NETSTARS model avails some good ideas of CHARIMA[4], BRALLUVIAL[5] and GSTARS[7] models to develop a powerful tool for resolving the problems of unsteady sediment process in a channel network. Since it is basically a 1-D model, secondary current and local scour can not be simulated by this model.

Equations for Hydraulic Routing

The de Saint Venant equations are used in the unsteady flow computation. These include the continuity equation and the one-dimensional momentum equation.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\beta\frac{Q^2}{A}\right)+gA\frac{\partial y}{\partial x}+gAS_f-\frac{Q}{A}q=0 \tag{2}$$

where A = channel cross-sectional area ; Q = flow discharge ; t = time ; x = coordinate in the flow direction ; q = lateral inflow/outflow discharge per unit length ; β=momentum correction coefficient; g = gravitational acceleration ; y= water surface elevation ;

$S_f = Q|Q|/K^2$ = friction slope; $K = \frac{1}{n} A R^{2/3}$ = channel conveyance; n = roughness coefficient of Manning's formula , and R = hydraulic radius.

Equations for Sediment Routing

The governing equations include a sediment continuity equation, a sediment concentration convection-dispersion equation and a bed load equation. The Rouse number $W/\kappa u_*$, where W = sediment fall velocity , κ= Von Karman's constant and u_* =shear velocity, is used to distinguish between bed load and suspended load. Particles with $W/\kappa u_* > 5$ are treated as bed load and particles with $W/\kappa u_* \leq 5$ are treated as suspended load. The sediment continuity equation is given as:

$$(1-p)\frac{\partial A_{d,k}}{\partial t} + \frac{\partial}{\partial x}\sum_{k=1}^{N_{size}} QC_k + \frac{\partial Q_b}{\partial x} = 0 \qquad (3)$$

where Q_b = bed load transport rate and C_k = depth-averaged concentration of the suspended sediment of size fraction k . A_{dk} = amount of sediment scouring/deposition per unit length and p =channel bed porosity.

The concentration C_k is calculated using the convection-dispersion equation shown as:

$$\frac{\partial (C_k A)}{\partial t} + \frac{\partial}{\partial x}(C_k Q) = \frac{\partial}{\partial x}\left(A k_x \frac{\partial C_k}{\partial x} \right) + S_k \qquad (4)$$

where k_x = longitudinal dispersion coefficients., and S_k = source term of the suspended sediment of size fraction k. The second term of equation (4) in the left hand side is the convection term. The first, second, and third terms of equation (4) in the right hand side are longitudinal dispersion, and reaction terms, respectively. According to Van Rijn [8] and Holly and Rahuel [3], the source term S_k is the combination of deposition and resuspension.

Armouring Scheme

The bed composition computation procedure is proposed by Bennett and Nordin [1]. According to this procedure the thickness of the active layer is set equal to a preselected parameter, N_t, times the geometric mean of the largest size class used in the simulation. The active layer is defined as the bed material layer that can be worked or sorted through by the action of the flowing water in the time step, t, to supply the volume of material necessary for erosion. The bed armoring is achieved by the erosion of a particular size of material being limited to the amount of that size available in the active layer during a time step.

COMPUTATIONAL PROCEDURES

The simulation processes consist of two parts in every time step, i.e., flow computations, and sediment routing. Flow computation is performed first. Then, sediment routing is performed to calculate the amount of channel bed variations. Eqs.1 and 2 are transformed into difference equations using a Preissmann four point finite difference scheme, and solving by double sweep method. The difference equation for the sediment continuity equation, i.e., equation (3), is shown as:

$$\Delta Z_i = \frac{-4\Delta t}{(1-p)(2P_i + P_{i+1} + P_{i-1})} \cdot \frac{\sum_{k=1}^{N_{ss}} [QC_k]_{k,j} - \sum_{k=1}^{N_{ss}} [QC_k]_{k,j-1} + Q_{sk,j} - Q_{sk,j-1} - q_{sk,j}\Delta X_i}{(\Delta X_i - \Delta X_{i-1})/2} \quad (5)$$

where ΔZ_i = variation of the bed elevation for every size fraction and P_i = wetted parameter. The concentration C_k is predetermined by solving the convection-dispersion equation, i.e., equation (4). The split operator approach is used in solving this equation. The governing equation is separated into three portions, i.e., convection, longitudinal dispersion, and reaction. They are solved subsequently in one time step. The C_k and CX_k values, where $CX_k = \frac{\partial C_k}{\partial x}$, obtained in the previous computation are served as the known values for the next computation. Holly-Preissmann two-point four-order scheme, Tee scheme, and analytical method are used to solve the C_k and CX_k values.

NETWORK ALGORITHM AND BOUNDARY CONDITIONS

The flow discharge at the nodal point has to satisfy the continuity equation, i.e., the summation of the inflow and outflow discharges from all the tributaries at a nodal point must be zero, or there is no storage at the nodal point. The nodal solution uses de St

Venant equations along the links between nodes to express the ΔQ values in terms of corrections to water surface elevations at the nodes. The solution algorithm comprises three phases for each iteration: namely, link forward sweep, node matrix loading and link backward sweep.

The bed elevation at a nodal point is assumed to be in an equilibrium condition, i.e., there is no net scouring and sediment deposition at the nodal point and total sediment flux at the nodal point equals to zero. Assuming the incoming sediment is fully mixed at the nodal point and then is distributed, according to the sediment transport capacity, to the downstream links. The bed load and suspended load are redistributed and treated separately at the nodal point.

A bed load equation is used to calculate the bed load transport capacity at the first section downstream of the nodal point and a rating curve to describe the relationship between the flow discharge and the bed load transport capacity, $Q_b = AcQ^{Bc}$ was established. Where Q_b=the bed load transport capacity, and Ac and Bc=constants to be calibrated. The outflowing bed load transport rate is distributed according to the bed load transport capacity obtained from the rating curve.

The suspended load is calculated by solving the sediment convection-dispersion equation using the split operator method. There are three portions, namely , convection , longitudinal dispersion and reaction, involved in the split operator method and each portion has to be treated differently at the nodal point. The split operator method had been applied in numerical solution of the one- and two- dimensional convection-dispersion equation by Cunge, Holly, and Verwey, 1980.[2] The algorithm used to split the sediment load at each node was originally proposed by Holly, Yang, et al. , 1990[5].

a. Convection: The sediment concentration C_t and corresponding concentration gradient are assumed to be fully mixed at the nodal point and then redistributed according to the weight of the flow discharge.

b. Longitudinal dispersion: Assuming net flux of the suspended sediment due to the longitudinal dispersion effect equals to zero at a nodal point.

c. Reaction: Since the suspended sediment is assumed fully-mixed at the nodal point and hence transverse dispersion and reaction treatments are not needed at the nodal point.

APPLICATION TO TANHSUI RIVER SYSTEM

The Tanhusi River system passes through Taipei area, and is one of the most important river in Taiwan. It consists of of three branches, namely, Keelung River, Hsindan Creek, Tahan Creek, and one flood by pass channel, is a typical channel network. The location map is shown in Figure 1. This network consists of 5 links, 6 nodes and 88 cross sections and is within the estuarine area. There is one gage station, namely, Taipei bridge (link 3, Sec.13) in the study area. These data, including water stages and channel bed variations, can be used to calibrate and verify the model. Field data from 1989, including geometric cross-sectional data and bed material data, are used as the initial condition. Data from 1989 to 1990 were used to calibrate the model and data from 1990 to 1991 were used for verification. The upstream inflow suspended sediment concentrations versus the inflow water discharge rating curves obtained by the Taiwan Provincial Water Resources Department are used for the upstream boundary conditions. At the downstream boundary, which is located at Tudigonbi (Link 1, Sec.1), the measured stage hydrographs are used as the downstream boundary

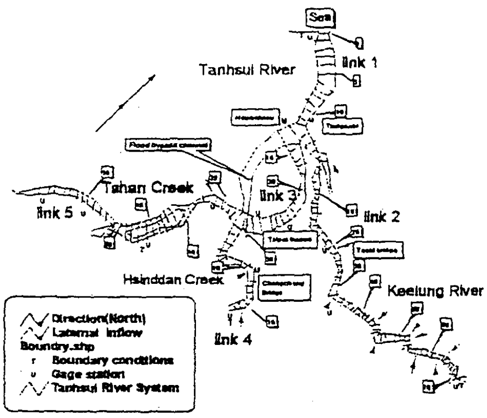

Figure 1. Location map of the Tanhsui River.

conditions. The model has to be "spinned" before real computation proceeds. A flow condition was assigned and let the model run until the water stages and discharges are smoothly-connected in the channel network, and this condition serves as the initial condition. The initial conditions for the sediment concentrations were then determined by the corresponding rating curves. The data of 1990 were used to calibrate the model. A time interval of 1 hour was used in the simulation and the total simulation period is 1489 hours. The N_t value of the thickness of the active layer is set to 1.0. The ranges of size fraction are from 0.016 mm to 16.0 mm.

Parameter Examination

The measured water stage data from five different gage stations were used to calibrate the Manning's *n* value of the model. The agreements are very good. The simulation results of Taipei bridge are shown in Figure 2. The simulated bed elevations for links 4 are shown in Figure 3. The agreements are satisfactory.

Verification

Using the parameters determined in the previous analysis, the model is applied to simulate the channel bed evolutions of Tanhsui River System from 1990 to 1991. The

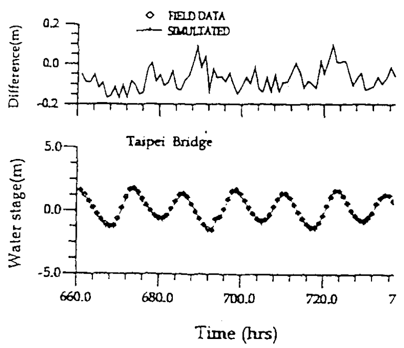

Figure 2. The calibrated water surface elevations at the Taipei Bridge.

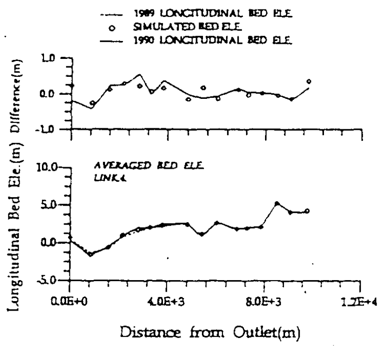

Figure 3. The calibrated longitudinal bed elevations for link 4.

total simulation period is 672 hours. The comparisons of the longitudinal water surface elevations, and longitudinal bed profiles are shown in Figures 4 and 5, respectively. The overall accuracy is good.

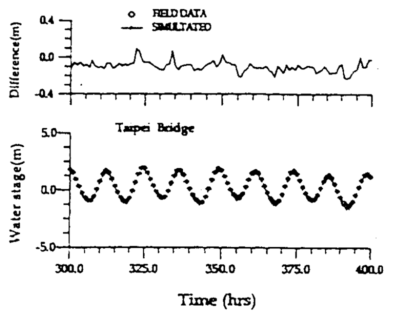

Figure 4. The verified water surface elevations at the Taipei Bridge.

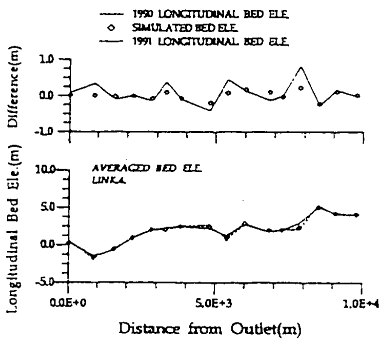

Figure 5. The verified longitudinal bed elevations for link 4.

CONCLUSIONS

A numerical model, which is capable of simulating scouring and deposition behaviors in a channel network under an unsteady flow condition, is developed in this study. A state-of-the-art sediment routing algorithm which is capable of simulating suspended and bed loads separately was developed in this model. An internal boundary condition based on the sediment transport capacity was proposed to distribute the incoming sediment load into the downstream links. The proposed measure is proved to be feasible. The model's performance and applicability have been demonstrated through an application to the Tanhsui River system.

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DAMAGE AND REHABILITATION WORK OF SHIH-KANG DAM

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On 21st, September 1999, the M_L7.3 (M_w7.6) Chi-Chi Earthquake was happened in the central region of Taiwan. Strong surface rupture, ground deformation, and ground motion damaged Shih-Kang Dam, locating at the end of Che-Lung-Pu Fault. Land survey, Ground and Penetrating Radar, Ultra Sonic, Borehole Camera, and Micro-tremor were done after the earthquake. The objective of this paper is to use these investigation results to describe the deformation of ground, the possible damage mechanism and behavior of Shih-Kang Dam during earthquake. The principle of emergent rehabilitation work is also described in this paper. The future investigation and research direction is suggested.

Key Words: Chi-Chi Earthquake, Seismic Fault-induced Failures, Shih-Kang Dam, Che-Lung-Pu Fault, Active Fault, Taiwan

1. INTRODUCTION

Shih-Kang Dam, which locates at downstream area of Da-Jia River, is the lowest dam of the cascade hydropower scheme that includes six hydropower plants and dams. On 21, September 1999, the M_L7.3 (M_W=7.6) Chi-Chi earthquake, also called 921 Earthquake, happened in the central region of Taiwan. The peak ground motion at station TCU084, locating at Sun-Moon Lake that is 10 km away from the epicenter, is 989 gal. The horizontal and vertical peak ground motion of the station TCU068, locating at Shih-Kang Primary School 500 meters away from Shih-Kang Dam, are 502 and 519 gal, respectively.

Shih-Kang Dam was damaged by marvelous surface ruptures of Che-Lung-Pu fault, strong surface deformation, and great ground motion. Since the Shih-Kang dam is the first concrete dam to be directly damaged by the active fault in the history of the hydraulic structures, the damage of Shih-Kang dam becomes very unique. Hence, it is very interesting to find out the causes of the damage, the behaviors of the damage, and the performance of damaged Shih-Kang dam. The experience from Shih-Kang Dam study will be very helpful to enhance the structural safety under similar situation in the other area.

The objective of this paper is to describe the observation of Chi-Chi earthquake and Che-Lung-Pu fault movement near Shih-Kang Dam, the investigation and damage behavior of Shih-Kang dam, and the emergent rehabilitation work. [1] The future investigation and research are suggested in the end of this paper.

2. BACKGROUND OF SHIH-KANG DAM BEFORE CHI-CHI EARTHQUAKE

Shih-Kang dam is a concrete gravity dam with tainter gates. The length of the dam crest of the Shih-Kang Dam is 357 meters. The height of Shih-Kang Dam from the foundation to the crest of the tainter gate is 21.40 meters. The top of the gravity dam is at elevation 272.2 meters. There are 18 spillways with weir crest elevation at 259.5 meters, and two sluiceways with weir crest elevation at 257 meters. The designed discharge of the spillways is 8000cms, and the spillways were controlled by 18 tainter gates, whose dimensions are 12.8m^{w}x8m^h. The possible maximum flood (PMF) was 13000cms with the elevation of the flood surface at EL. 270.0 meters. In the sluiceways, there are two 8m^{w}x6m^h tainter gates and the parapet walls from the top of the sluice gates, at elevation

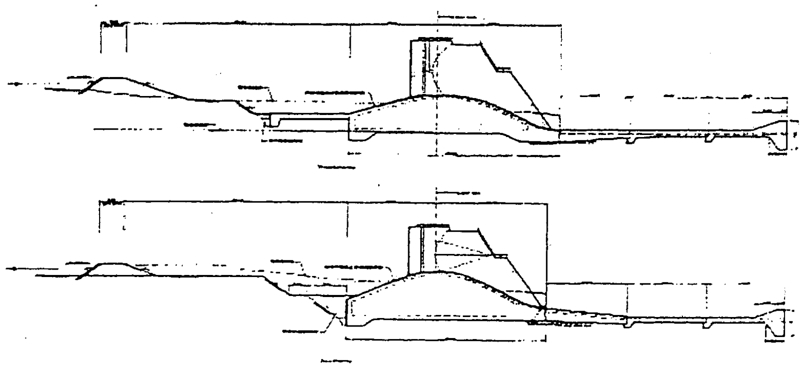


Figure 1 The Cross Section of Shih - Kang Dam

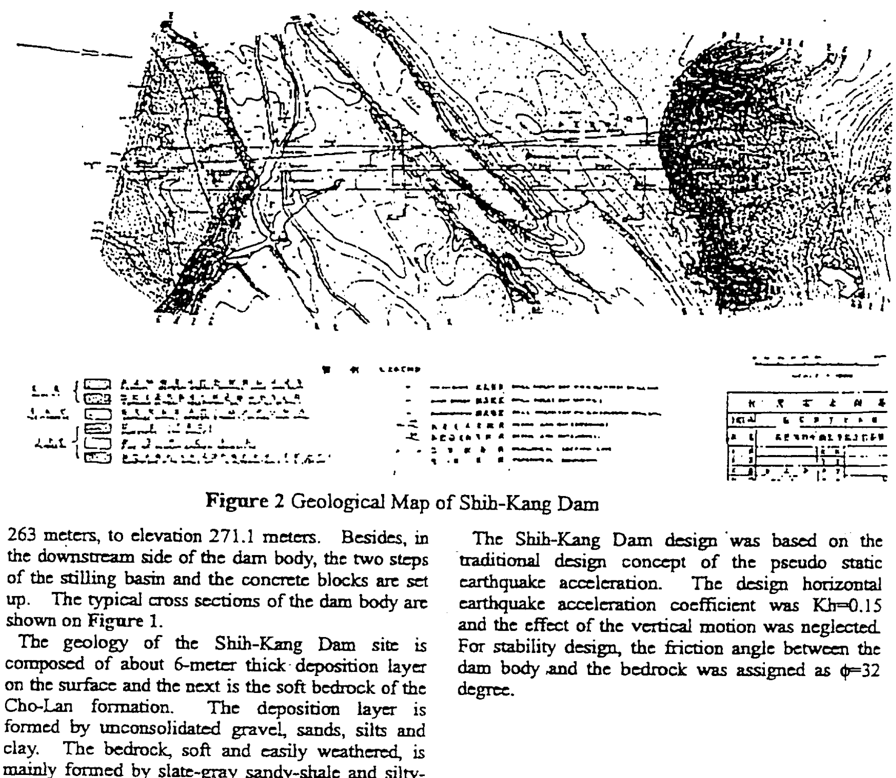


Figure 2 Geological Map of Shih-Kang Dam

263 meters, to elevation 271.1 meters. Besides, in the downstream side of the dam body, the two steps of the stilling basin and the concrete blocks are set up. The typical cross sections of the dam body are shown on Figure 1.

The geology of the Shih-Kang Dam site is composed of about 6-meter thick deposition layer on the surface and the next is the soft bedrock of the Cho-Lan formation. The deposition layer is formed by unconsolidated gravel, sands, silts and clay. The bedrock, soft and easily weathered, is mainly formed by slate-gray sandy-shale and silty-sandstones. The foundation of the Shih-Kang Dam sits on the bedrock of the Cho-Lan formation. The geological map is shown on Figure 2.

The Shih-Kang Dam design was based on the traditional design concept of the pseudo static earthquake acceleration. The design horizontal earthquake acceleration coefficient was K_h=0.15 and the effect of the vertical motion was neglected. For stability design, the friction angle between the dam body and the bedrock was assigned as ϕ=32 degree.

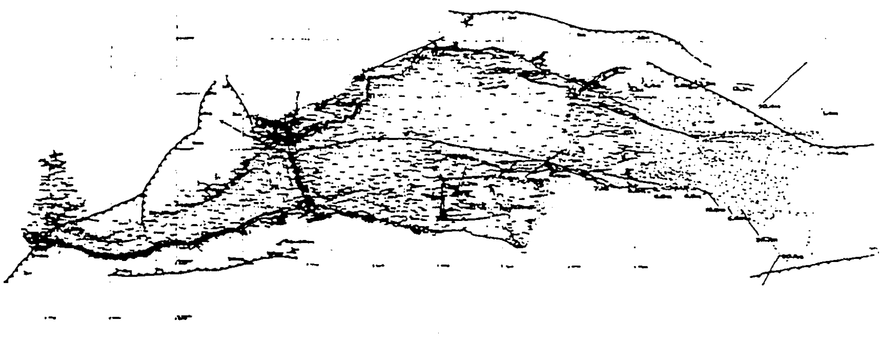


Figure 3 Surface Ruptures and Displacement near Shih -Kang Dam

3. DAMAGE INVESTIGATION AND BEHAVIOR OF SHIH-KANG DAM

3.1 Deformation

During Chi-Chi earthquake, the deformation of the Shih-Kang Dam and ground surface deformation in the vicinity of this dam were very complicated. In this paper, there are three different kinds of deformation, based on their magnitudes and locations, presented as follows.

(1) *Surface Rupture*

The surface ruptures, caused by the active faults near the Shih-Kang Dam,, are shown on Figure 3. They are the fragments of the surface ruptures of the Che-Lung-Pu fault. The total rupture length of the Che-Lung-Pu fault is about 75 km. During Chi-Chi earthquake, the total rupturing time of the fault was about 30 seconds, and the spreading speed of the surface rupture was about 2.5 km per second. Upon the geodesic survey/GIS survey, remarkable permanent ground surface displacement was observed in the central region of Taiwan. For instance, the longitudinal and latitudinal permanent displacement of the Station TCU068 are 5 meters north and 7 meters west. The vertical rupture uplift gradually increases from the south to the north of the Che-Lung-Pu fault. The more southeastern it was, the smaller permanent ground surface displacement was caused by the Chi-Chi earthquake. The horizontal and vertical displacement along the Che-Lung-Pu fault is shown on Figure 4 and 5. In addition, the permanent ground surface displacement shows that the terrain, between Che-Lung-Pu Fault and Li-Shan Fault, is tilted toward the northwest. In 60km east away from the Che-Lung-Pu fault, the permanent displacement is about 30 cm.

10 boreholes were done in the upstream of dam near No.16 spillway. The depth of silt rock shows an abrupt change within 2-meter width of bend. The foundation bedrock is at 6 to 7.5 meters depth in the left side and at 9 to 18 meters depth on the right side. It is direct evidence to show the rupture line of the fault is at the right pier of No.16 Spillway and is extended to the upstream of the dam.

(2) *Surface Deformation near Shih-Kang Dam*

Geodesic survey, of which the reference point was Hou-Li that is on the footwall side and 10km away from the Che-Lung-Pu fault, was done on October and December 1999. The topography of the geodesic survey is shown on Figure 3. Compared with the former survey on May 1999, before Chi-Chi earthquake, the terrain was deformed toward the northwest and the left bank of Da-Jia River was moved by about 10 meters north. The riverbed of Da-Jia River was risen by about 3-4 meters to 10 meters only in the range of 3 km along the river. Wavy deformation of the ground surface in the upstream of the Shih-Kang Dam can be observed; the surface deformation in the downstream of the dam shows a bow-shape and uplifted terrain. The uplift contour map around Shih-Kang dam area is shown on Figure 6. On average, the deformation slope is around 0.2% to 0.6% in cross-river direction. Deformation slope along the flow direction is around 0.5% to 2%. Deformation slope can be 2 to 5% at some local places. Typical cross section of the deformed riverbed is shown on Figure 7. Deformation slope, which means the difference in vertical uplift height between two points is divided by the horizontal distance between them, can be calculated from the topography.

The deformation of the terrain near Shih-Kang dam is as follows:

1. Deformation at the downstream Shih-Kang Dam is about 10 meters of uplift. Uplift at first step stilling basin ranges from 10 meters to 10.9 meters. Slope at the first step stilling basin is around 0.3/60=0.5%. The uplift at the second

Figure 4 Horizontal displacement along Che-Lung-Pu Fault

Figure 5 Vertical displacement along Che-Lung–Pu Fault

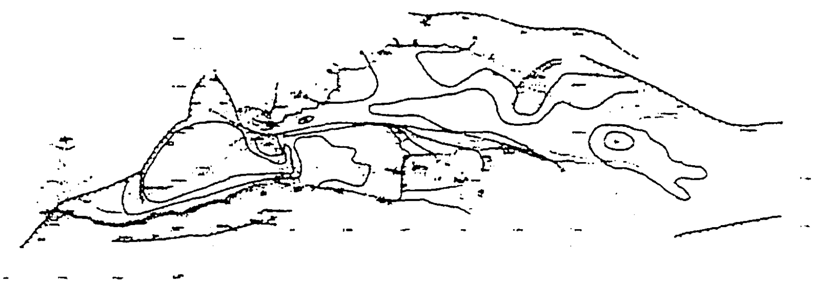


Figure 6 The Uplift Pattern of Ground near Shih -Kang Dam

step stilling basin is between 9.2 to 11.0 meters. Thus, there is 1-meter drop in the flow direction between the two steps of stilling basins. Uplift at the right abutment of the dam is about one to two meters.

2. Vertical uplift across the fault is around 10 meters.
3. Average deformation slope from left bank to right bank of the Da-Jia River is around 1.8/150=1.2%.
4. Riverbed in the downstream of Shih-Kang dam is uplifted by about 8 meters. In this area, the relative deformation slope was around 2%.
5. Uplift is about 7 meters near the Bei-Fung Bridge on the hanging wall side of Che-Lung-Pu fault.
6. From 50 to 1000 meters upstream riverbed of the dam, there are different deformation slopes. For example, for the first 300 meters, the uplift changes from 8 to 10.5 meters along the flow direction. The average deformation slope is around 0.9%. From 400 meters to 600 meters

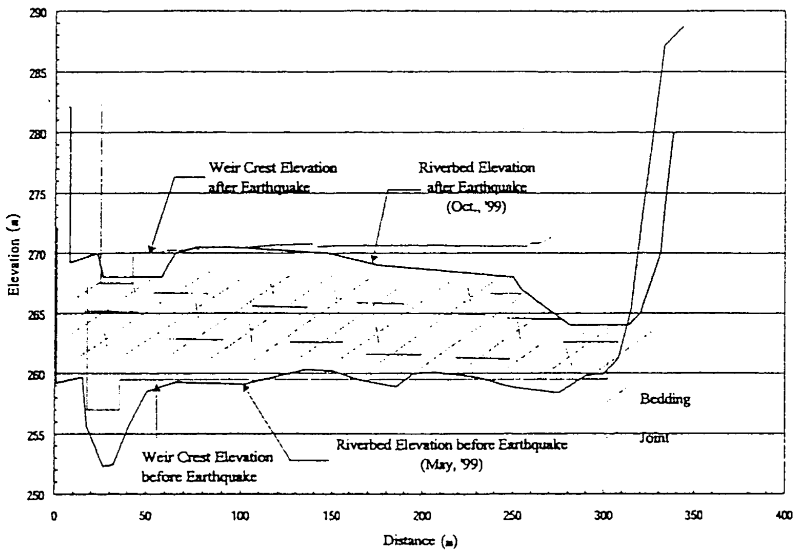


Figure 7 Elevation of weir crest and riverbed 40m upstream from Shih-Kang Dam before and after earthquake

upstream riverbed of the dam, deformation is around 5/130=4%. From 600 meters to 1 km (in the downstream of Chang-Geng Bridge) upstream riverbed of dam, the uplift is around 4.0 meters. Deformation slope is around 0.1%. From Chang-Geng Bridge, at 1200 meters upstream of dam, to 1700 meters upstream riverbed of dam, uplift is about 3.0 meters to 6.0 meters. Local deformation slope is around 0.6% to 0.1%. The maximum deformation slope is around 2% along the flow direction.

7. In the first 600 meters upstream of dam, uplift in the left part of the riverbed of the Da-Jia River is around 8 to 10 meters. Uplift in the right part riverbed of the Da-Jia River is around 4 to 6 meters. Sharp difference between slopes of the right and the left part of riverbed is shown at 100 meters upstream of dam. From 600 meters to Chang-Geng Bridge upstream of dam, the uplift in the left part of the riverbed is around 5 to 8 meters. The uplift in the right part of the riverbed is around 4 to 6 meters. The sharp difference uplift is in the left part of the riverbed. In the upstream of the Chang-Geng Bridge, uplift in the left part of the riverbed is around 3 to 5 meters and uplift in the right part of the riverbed is around 3 to 6 meters. Uplift in the hanging wall side of the fault is around 7 meters. Deformation slope of this hanging wall is about 3 to 3.5%.
8. Vertical uplift exists at center of river from the broken dam to the rupture of Chang-Geng Bridge. Surface rupture may be aligned from the broken dam to the east of Chang-Geng-Bridge.

(3) *Deformation on the Shih-Kang Dam*

The impact of the fault burst caused different levels of displacement between the dam and the stilling basin. **Figure 8** shows the deformation of the weir crests of the Shih-Kang Dam. The maximum different elevation of the weir crests is around 1.5 meters. The maximum horizontal displacement of weir body is 35cm towards the upstream direction at the No. 8 spillway. **Figure 9** shows the deformation slope of every weir crest of Shih-Kang Dam. Another way to observe the dam deformation along the dam axis is to check the relative deformation of the trunnion girders of the tainter gates, shown on **Figure 10**. Besides, cracks are found on the stilling basin.

The remarkable deformation of the piers caused the pier concrete cracks. Besides, the length of the dam axis is shortened by about 7 meters; namely,

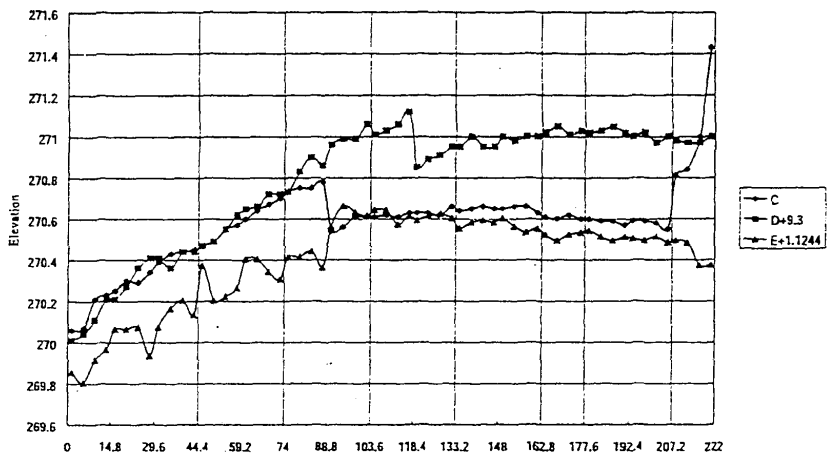


Figure 8 Deformation of weir crest of Shih-Kang Dam

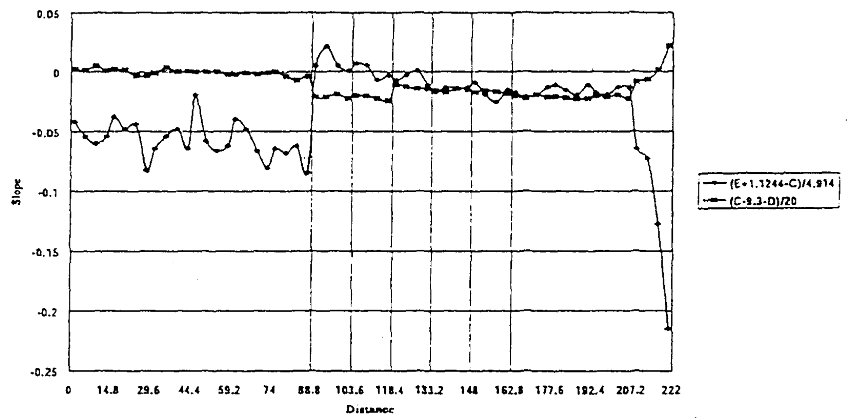


Figure 9 Deformation slope of weir surface of Shih-Kang Dam in flow direction

the dam was heavily compressed during Chi-Chi earthquake. In general, there are two phenomena. First, the larger deformation slopes of the ground surface, the worse damage to the dam can be found. Second, the dam body was tilted towards the downstream direction and twisted towards the counter-clockwise direction as facing to the downstream direction.

Results of new elevation measurement are shown on Table 1. The relative positions in each weir body are shown on Figure 11. The vertical distance between point D and point C was 9.3 meters before earthquake, and the vertical distance between C and E was 1.1244 meters. The table 1 shows two different deformation patterns. First, from spillway No.8 to Spillway No.14, the point D was tilted upward with 40 cm of displacement. The average deformation slope along the flow direction was around 2%. The point E moved 10 cm downward relative to point C and the average deformation slope between E and C is around 2.03%. Second, from Spillway No.1 to No.6, the relative

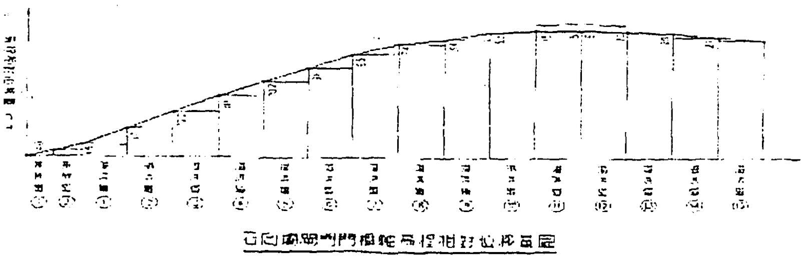


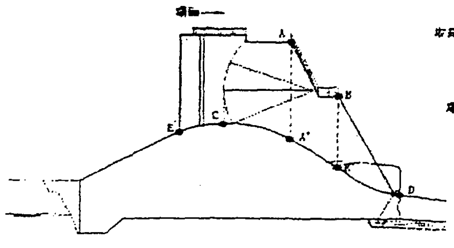
Figure 10 Relative deformation of trunnion girders

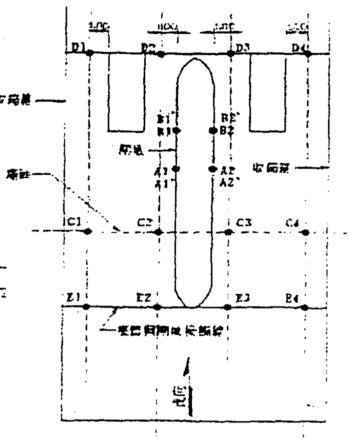
Table 1 Elevation Measurement of Weir Bodies and Piers

No.	EL of SL2	EL of SP1	EL of SP2	EL of SP3	EL of SP4	EL of SP5	EL of SP6	EL of SP7	EL of SP8	EL of SP9	EL of SP10	EL of SP11	EL of SP12	EL of SP13	EL of SP14	EL of SP15
A1	280.74	280.83	280.98	281.13	281.25	281.34	281.45	281.57	281.63	281.67	281.7	281.76	281.71	281.68	281.69	281.64
A1'	266.08	268.44	268.46	268.44	268.29	268.96	268.91	269.07	269.15	269.08	269.2	269.07	269.11	269.21	269.08	269.1
A2	280.4	280.45	280.6	280.73	280.88	281	280.1	281.22	281.34	281.4	281.45	281.45	281.51	281.47	281.44	281.41
A2'	268.29	268.45	268.46	268.55	268.82	268.94	268.99	269.1	269.08	269.23	269.25	269.17	269.09	269.13	269.25	269.14
B1	273.65	273.83	273.94	274.08	274.18	274.34	274.48	274.57	274.71	274.74	274.77	274.78	274.76	274.78	274.75	274.73
B1'	263.61	265.47	265.81	265.97	266.06	266.14	266.33	266.19	266.39	266.7	266.66	266.63	266.69	266.79	266.81	266.63
B2	273.67	273.82	273.94	274.07	274.2	274.34	274.5	274.6	274.72	274.76	274.76	274.77	274.79	274.78	274.75	274.79
B2'	265.77	265.77	265.84	265.98	266.09	266.27	266.13	266.43	266.86	266.62	266.77	266.73	266.26	266.74	266.93	266.68
C1	267.47	270.06	270.25	270.39	270.47	270.6	270.73	270.54	270.61	270.63	270.64	270.65	270.61	270.6	270.59	270.81
C2	267.54	270.07	270.3	270.43	270.49	270.64	270.75	270.56	270.62	270.63	270.65	270.66	270.6	270.59	270.59	270.84
C3		270.21	270.29	270.44	270.55	270.67	270.75	270.61	270.61	270.62	270.66	270.66	270.62	270.59	270.58	271
C4		270.23	270.34	270.45	270.57	270.7	270.78	270.61	270.63	270.66	270.65	270.63	270.6	270.57	270.55	271.43
D1	259.9	260.71	260.91	261.11	261.17	261.35	261.43	261.66	261.71	261.55	261.65	261.7	261.72	261.72	261.7	261.68
D2	259.64	260.74	260.97	261.06	261.19	261.36	261.53	261.69	261.73	261.59	261.7	261.68	261.75	261.73	261.72	261.67
D3		260.81	261.06	261.14	261.25	261.42	261.6	261.69	261.76	261.61	261.65	261.7	261.71	261.75	261.67	261.67
D4		260.91	261.11	261.14	261.32	261.42	261.56	261.76	261.82	261.65	261.65	261.7	261.73	261.72	261.7	261.7
E1		268.73	268.94	268.95	269.25	269.28	269.29	269.44	269.52	269.47	269.43	269.48	269.4	269.42	269.38	269.37
E2		268.68	268.94	269.04	269.08	269.28	269.29	269.54	269.52	269.49	269.46	269.44	269.37	269.39	269.37	269.36
E3		268.79	268.95	269.08	269.1	269.22	269.32	269.51	269.45	269.5	269.47	269.41	269.4	269.37	269.39	269.25
E4		268.84	268.81	269.01	269.14	269.18	269.24	269.49	269.49	269.48	269.46	269.43	269.41	269.39	269.36	269.25

movement of point C and D was very little. Point E moved around 30 cm downward relative to point C and the average deformation slope along the flow direction is about 4% to 6%. The deformation slopes of the point D have a dramatic change at about spillway No.8 to No.9 with 17 cm vertical uplift difference. The deformation slope on these two spillways is around 1.9%. The deformation slopes of the point C have a dramatic change at about spillway No.8 to No.9 with 17 cm vertical uplift difference.

The relative vertical uplift of each weir body along the dam axis is a few centimeters. The deformation slope along the dam axis direction is





around 0.5% to 2%. The maximum slope is about 3%. The interesting issue is that point C, D, E, on the right part of the dam is lower than on the left part for spillways No.9 to No.14. For spillways No.1 to No.8, point C, D, E on the left part of the dam is lower than on the right part. This phenomenon reflects that the ground deformation has a Crown Point on spillway No.8 with a large displacement.

3.2 Ground Motion and Movement

During Chi-Chi earthquake, the Shih-Kang Dam moved towards northwest and upward. The permanent displacement measurement can also show the moving direction of land. Figure 3 shows the location relative to the reference point before and after earthquake. The moving direction of LS05, LS06, LS08 is north. The moving direction of LS11 to LS17 is northwest. Due to the footwall effects, point LS18 is towards southwestern direction. Due to effects of surface rupture, point RS14, RS15, RS16, locating on footwall side of fault rupture, move east. Point RS11, RS12, RS13 move to the northwestern direction. Point RS4, RS5, RS6 and RS7 move to the northeastern direction. Point RS9 is strangely moves to the southeastern direction. In general, moving direction also reflects the surface rupture characteristics and the deformation pattern of ground surface.

The accelerogram of Chi-Chi earthquake of the Station TCU068, shown on **Figure 12**, shows the peak ground acceleration was about 520 gal. From the Figure 12, the ground motion of Chi-Chi earthquake can be described as follows. The first notably strong ground motion, caused by the fault impact pulse, lasted for about one second and started from the upward with northwestern direction, which was perpendicular to the fault line. Then, the notably strong ground accelerations in the southeastern and southwestern direction came a little later than the first shock. This may be explained by the acceleration caused by the reflecting vibration wave. The following downward with northeastern and downward with northwestern may be explained to be caused by the land vibration wave. Then, the strong ground motion also made the remarkable permanent displacement on the dam site. There ware about 10-meter vertical movement and 11-meter horizontal movement on the dam site surface. The movement of the top of the No. 2 intake structure was about 9.978m up, 7.0734m north and 0.9853 east. In general, the Shih-Kang Dam rupture damage mainly came from the vertical and north-south direction of the ground motion.

From the Figure 12, the main velocity was from about 33.5 seconds to 45 seconds. The main shock happened between 33.5 seconds and 40 seconds. During this period, the direction of ground movement was in the upward and northwestern direction. The peak velocity of vertical and the northwestern motion is around 220 and 300 cm/sec, respectively. Therefore, the direction of ground movement is towards up and northwest. From 33.5 seconds to 38 seconds, the vertical movement is around 489 cm and the horizontal movement is 918 cm north and 649 cm west. Comparison with ground movement datum of Shih-Kang Dam, the TCU068 data gives the similar results. Based on investigation of Shih-Kang Dam, the near fault

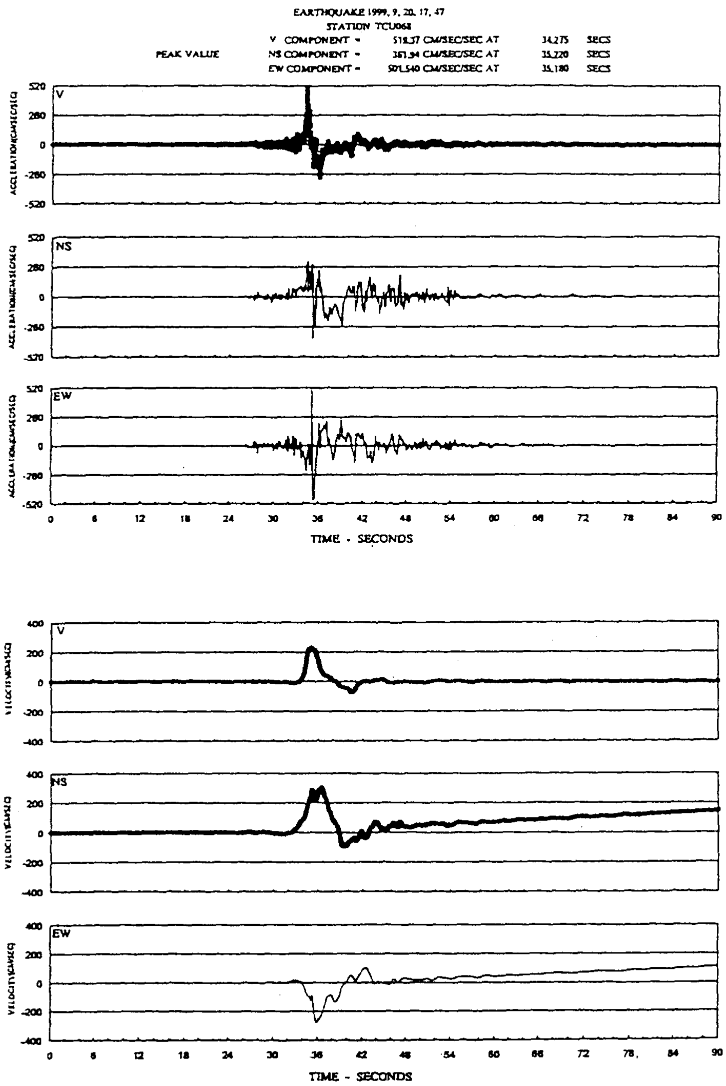


Figure 12 The Time History of Accleration and Velocity at TCU068

movement is around 10m. This is very huge ground movement and causes a terrible impact to the structures and lands, restraining from the ground motion. [2]

3.3 Damage Behavior

Shih-Kang Dam was damaged by strong motion of earthquake, remarkable rupture of fault, and large displacement of ground surface. Since the ground deformation was greater than the allowable deformation of the dam massive concrete body, it caused the dam body crack and separation of dam body from foundation bedrock. The seismic investigation results show that almost every dam body was separated from foundation bedrock and, in most spillways, there were three main sets of horizontal cracks developed their depth. The first one is around 1.5 to 2 meters deep. The second one is about 5to 6 meter deep. The third one is about 7.5 to 8.5 meters deep. Usually, the cracks developed along the construction lift line.

The echo-impact investigation results show that a crack depth on No.8 spillway is about 1.65 to 2.1 meters and one of cracks on spillways No.9 may penetrated through the dam body. There is a crack of about 1.45 meters deep on No.10. The borehole camera was used to investigate the damage of No.8 spillway. The results show that horizontal cracks were found at 1.6-1.7 m and 6.9-7.0 m beneath the weir surface. Dam body and foundation bedrock of No.8 spillway were separated by the earthquake. There were vertical cracks penetrated to the depth 8.2 to 8.4 meter on No.8 weir body. The second borehole camera data shows the similar results to the first one. The investigation results tell the No.8 and No.9 spillways was heavily damaged, and the horizontal and vertical cracks were developed inside the weir body. The weir body has possibly been fractured from bottom to the top. The micro-tremor measure also showed the similar results.

The damage of Shih-Kang Dam can be defined as different types. The first type of damage came from the effects of the large ground motion, the ground surface displacement, and the deformed or broken foundation bedrock, of which bearing capacity was somehow reduced. This type of damage can be seen on No. 1 to No. 15 spillways. In addition, the No. 8 to No. 15 spillways have severer damage than the No. 1 to No. 7 spillways. The vertical uplift and strong deformation of the ground surface can be evidenced from measurement along the cross section 0-0, adjacent to the dam in the upstream side, on Figure 7. Figure 7 also shows the bedding plans of the foundation bedrock and the deformation of the hanging wall of the fault along the dam axis. Obvious damage of the first type is the displacement of the dam bridges, the deformation of the tainter gates, and the cracks of the piers.

The second type of damage is an impact type. This is the strong contact impact of every adjacent weir body during the earthquake. The evidence of this type is the shorten length of the dam axis of the Shih-Kang Dam by about 7 meters. Another evidence of impact type can be found out by integrating the acceleration of **Figure** 12. Velocity of ground motion has been in the vertical northwestern direction through the whole duration of Chi-Chi earthquake. The obvious damages of the second type are weir body cracks and the extended cracks on the piers.

The third type of damage is the fault rupture type. This type is the combination of rupture effects, strong ground motion, and huge impact, etc. Thus, this one is the most complicated type. The obvious damage of the third type is on the No. 16 to No. 18 spillways and the right abutment of the dam. Through surface investigation, ~45 degrees of fracture pattern is shown on the surface of the weirs of the dam. This fracture pattern of weir bodies and stilling basin is shown on **Figure** 13. Some of the fracture penetrated through the weir body.

In addition, **Figure 14** shows the damage pattern of the right abutment. The right pier of No.18 spillway shows a diagonal crack, a shear-induced-fracture, on the bottom of the pier. The right abutment shows several diagonal cracks on the lateral wall. The cracks also developed along the construction lift line. These cracks also developed on the dam body. The retaining wall, connecting to the right abutment, had two diagonal cracks and slid downward to the river. The tainter gates of No. 17 and 18 spillway show severe buckling damages. The pier between No.17 and No.18 is tilted and completely cut, shown on **Figure** 15. The cut cracks developed towards the 45 degrees. In addition, The dam body between spillways No.16 and No.17 was completely damaged. The strong impact and uplift force of active fault damaged the dam body, shown on **Figure 16**.

Another interesting damage behavior was the pier No. 2, locating between No. 2 sluiceway and No.1 spillway. This pier was completely cut as shown in **Figure** 17. The fracture of this pier resulted from not only the effects of the impact action and the ground motion, but also the effect of the tremendously different stiffness of the structure system because there was the parapet wall built only on the sluiceway side, but none in the spillway side. This character of the large difference in stiffness is the cause of the disaster of the pier No. 2.

4. STRATEGY OF EMERGENT REHABILITATION WORK

Shih-Kang Dam is one of the most important water resource facilities for Tai-Chung area which

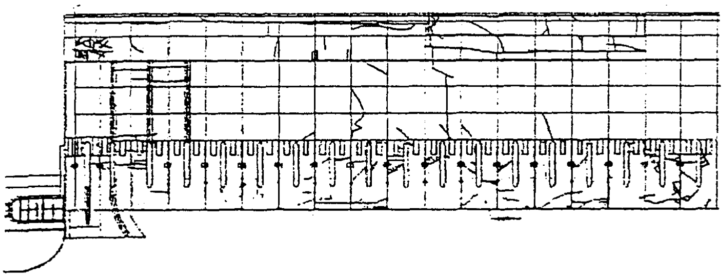


Figure 13 The Fracture Pattern of Weir Bodies and Stilling Basin

Figure 14 Damage pattern of right abutment

Figure 15 Broken pier between No. 17 and No. 18 spillways

has more than one million inhabitants. After the Chi-Chi earthquake, the emergent task was to restore the water supply function and ensure the sustainability of this dam in the coming flood season. The strategy of the emergent work was the following: First, evaluate the possible storage capacity of the damaged Shih-Kang Dam and the deformed riverbed of the reservoir area. Upon the

Figure 16 Dam body damaged by strong impact and uplift force

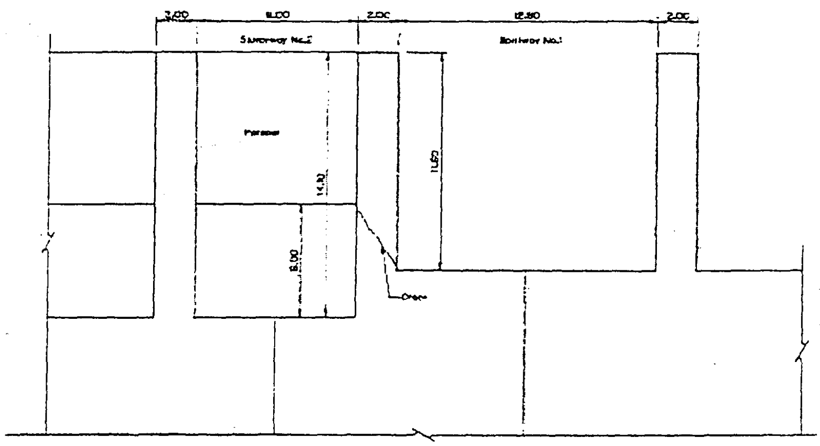


Figure 17 The Damage Behavior of the Pier between Spillway No.1 and Sluiceway No.2

preliminary evaluation of the damaged dam, the possibly allowable maximum reservoir water level is 273.0 meters that is 2.5 meters high from the average elevation of the spillway weir crests. The water storage capacity is reduced to 400,000 cubic meters. (original capacity: 2,700,000cubic meters) Second, evaluate the intake capacity of Shih-Kang Dam. If the water level elevation is at 270.5 meters, the average elevation of spillway weir crests, the maximum intake discharge is 23.33 cms, which are about 52% of the design discharge capacity of the first intake, 45.167cms, before the earthquake. If the water level elevation can be risen to EL. 272.37 meters, the intake discharge capacity can be 45.167 cms.

Considering the existing active fault on the dam site, the long-term solution to the damaged Shih-Kang Dam and Tai-Chung area water resource is to build a new reservoir in the upstream of Shih-Kang dam to substitute for the damaged one. Before the accomplishment of the new reservoir, Shih-Kang dam needs to maintain its remnant function. In order to prevent the dam from the further damage by the coming flood season starting from May 2000, the emergent rehabilitation work was carried out in an economic, efficient, and effective way. Namely, the purpose of the work is for emergency only. The rehabilitation work, shown on Figure 18, included the followings: (1) intake tunnel, which was cut by the fault; (2) intake structure, which was fractured by the land movement; (3) wing wall of the left abutment, which overturned in the

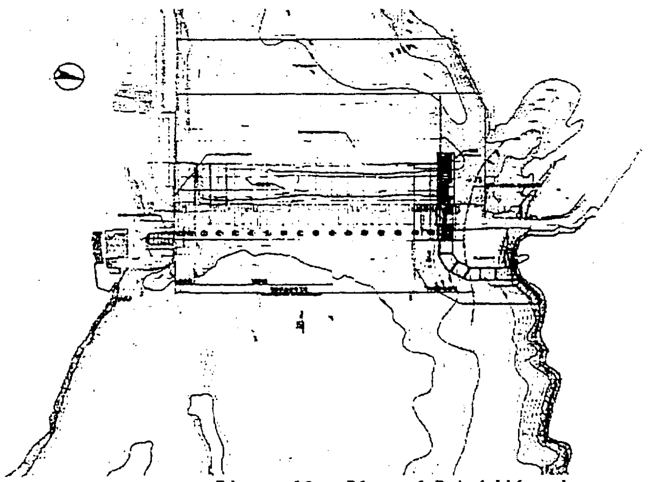


Figure 18 Plan of Rehabilitation

earthquake; (4) sluiceways and spillways; (5) stilling basin; (6) downstream tail dam; (7) tainter gates; (8) the right part of the dam, which was precisely on the fault rupture aligning area; (9) dam bridges. In the meantime, the damage investigation was launched.

The first phase of the rehabilitation work was to repair the intake structure and tunnel. The ruined concrete lining tunnel was coated by steel pipe lining. Besides, The wing wall of the left abutment was rebuilt. The second phase of work was to repair the dam-body out of the fault aligning area. The cement grouting was taken in the dam foundation and epoxy cement was injected into the cracks of the dam-body and stilling basin. . The quantity of grouting is shown on Figure 19, which shows the serious damage foundation bedrock from spillway No. 8 to No. 15. The new downstream tail dam was installed to make the downstream water level rising to slow down the velocity of the river current or flood in the stilling basin.

The third phase of the rehabilitation work was to reserve the right part of the dam, which locates on the fault aligning area, to be a memorial of Chi-Chi earthquake. The work is to install a cofferdam in front of the right part of the dam to prevent it from the damage of the river current or flood.

5. DISCUSSION AND SUGGESTION

Shih-Kang Dam was seriously damaged in Chi-Chi earthquake. The main causes of the damage were the large ground surface displacement, ground motion, and fault burst. It is interesting to mention the structures on the hanging wall of the fault had more serious destruction than on the footwall side of the fault. Obviously, the hanging wall deformation due to the Che-Lung-Pu fault rupture caused the failure of the Shih-Kang Dam.

Detail investigation on the dam area provided a lot of information. First, the deformation of dam body was affected by the stiffness of the structures. Second, The deformation of the surface deposition layer was different from the solid rock. Third, the different level of the structural deformation near fault area depended on its material property, geometry, kinematics, ground motion, landform, and geology.

Forth, the traditional pseudo static earthquake design method gave well-performance on the gravity concrete dam, Shih-Kang dam. Although the original pseudo static horizontal acceleration of the dam was much less than the real peak horizontal acceleration of the Chi-Chi earthquake and the sliding failure of the dam did happen. Except the fault aligning area, the dam still remains in a repairable condition. Besides, in spite of the damaged dam, there was almost no consequent damage on the dam by the river current or flood.

The investigation showed the damage of the Shih-Kang Dam was very complicated and the appropriate investigative instruments are needed. There were some very helpful investing instruments in the investigative work. For example, the high intensity and resolution of Ultra Sonic, Ground and

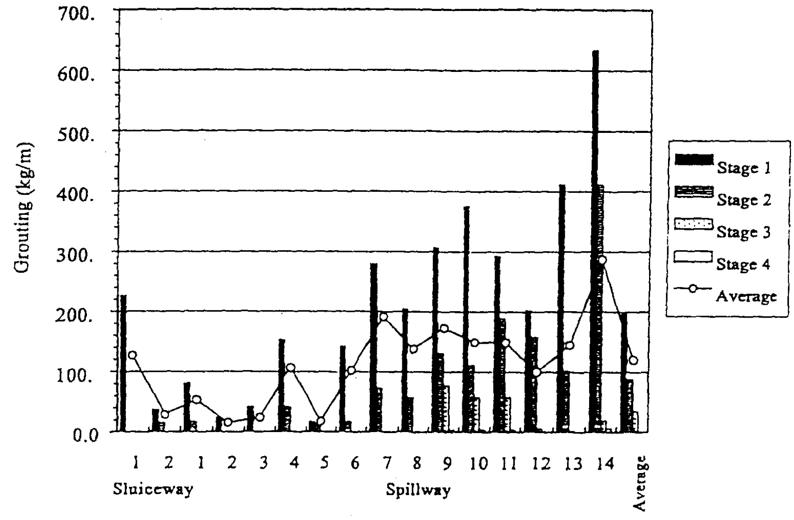


Figure 19 Consolidation Grouting Quantity

Penetrating Radar equipment were very helpful for investigation, and the borehole camera was a very good tool to observe the fracture situation of the massive concrete weir body and foundation bedrock. The cross-hole seismic data was very useful to understand fracture orientation and fracture characteristics.

In addition, because there is much data and information of Chi-Chi earthquake and Che-Lung-Pu fault recorded and investigated, it is very helpful for the future planning, design and construction of civil structures near the fault area.

Finally, there are some suggesting questions. 1. "Can we use a traditional ground motion model to analyze the dam behavior during strong impact and large ground surface displacement? & How to modify the current design concept?" 2. "How to set up the boundary condition and parameters for the structures under strong velocity action or on the fault rupture?" 3. "Shall we change the properties of structures and foundation from elastic to elasto-plastic because of strong earthquake or fault rupture?" 4. "How to add fault movement to the structural analysis model in the proper way?" All these questions needs further researches.

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Brief Report on Reservoir Sedimentation Survey in Taiwan 2000

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INTRODUCTION

Reservoirs in Taiwan generally have small capacities and high sedimentation rates. Constructing new reservoirs to replace the silted-up ones is still the major alternative for developing water resources, but this approach is being impeded by the declining availability of dam sites, increasing costs, and environmental concerns. Hence, there is a need for more precise reservoir bathymetric survey techniques and for research into sedimentation processes in order to guide the periodic dredging of existing reservoirs so that they may continue to fulfill their original design functions.

As the research group of the AIT-TECRO Water Resources Program, faculty members from the Field Survey Laboratory of the Hydraulics and Ocean Engineering Department of National Cheng Kung University (NCKU) have submitted a paper concerning the current status of reservoir sedimentation surveys in Taiwan. Included are some comments on the draft "Reservoir Sedimentation Monitoring Procedure," issued by the U.S. Bureau of Reclamation (USBR) at the 12th AIT-TECRO Water Resources Program Annual Meeting in 1999. Summaries are presented below for two of the group's current (1999-2000) studies: "Reservoir Sedimentation Survey Research in Taiwan 2000" and "Suggestion of Reservoir Sedimentation Survey Manual Suitable for Taiwan Area."

RESERVOIR SEDIMENTATION SURVEY RESEARCH IN TAIWAN 2000

RTK GPS Positioning

Trimble 4700 series DGPS/RTK GPS receivers were used for the testing of fast static and dynamical identity (photo 1) at the NCKU campus during the period of June 5–28, 2000. After data processing, the error in the fast static survey was determined to be only

0.0092m. During dynamic testing, the moving trace position was found to firmly match the campus map.

Photo 1. RTK GPS dynamical identity test.

RTK GPS / DGPS Testing

The same DGPS/RTK GPS receivers described above were used for accuracy testing of both DGPS and RTK GPS on June 28 and 29, 2000. The results are illustrated in figures 1 and 2. They show that the 95% confidence level of horizontal positioning error in RTK GPS is about 1.3 cm and its maximum error is about 4.8 cm. For DGPS positioning, the error radius at the 95% confidence level is about 1.1 cm, and the maximum error is about 8.6 cm.

Operating GPS Cooperatively with Conventional Positioning

The Trimble TTS 500 Laser Terrestrial Total Station (photo 2) can be operated by the same TSC1 survey controller used for the Trimble 4700 DGPS/RTK GPS receiver. This allows the TTS 500 to be used cooperatively with the GPS receiver. The hand-held Adventage Laser Rangefinder can also be used simultaneously with the GPS antenna (photo 3). Both of these instruments were tested against a conventional supplementary

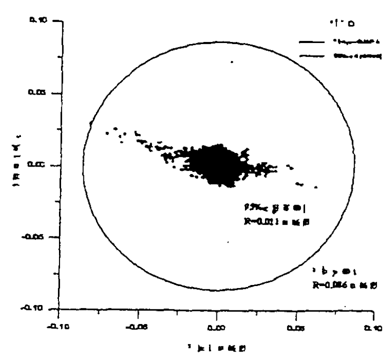

Figure 1. DGPS positioning error radius.

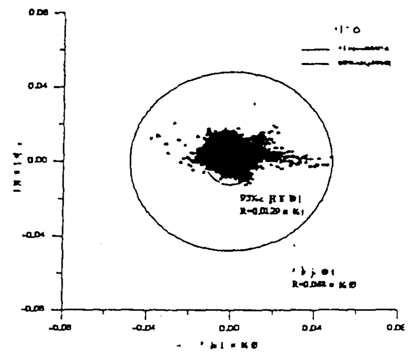

Figure 2. RTK GPS positioning error radius.

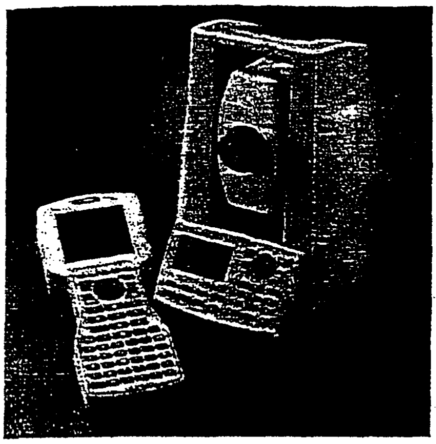

Photo 2. Trimble TTS 500 with TSCI controller.

Photo 3. Advantage Laser Rangefinder with GPS antenna

survey by NCKU to verify their positioning precision during times when the GPS signal is blocked or the radio link is interrupted.

Depth Sounding

Single-beam echo sounders are still widely used by hydrographic survey systems in Taiwan. Few multi-beam sounding systems are applied to bathymetric surveys because of their high cost. Hence, NCKU has adapted the underwater SONAR scan system (figure 3) for use in inspecting bottom conditions, in order to assess and adjust the line spacing during bathymetric surveys.

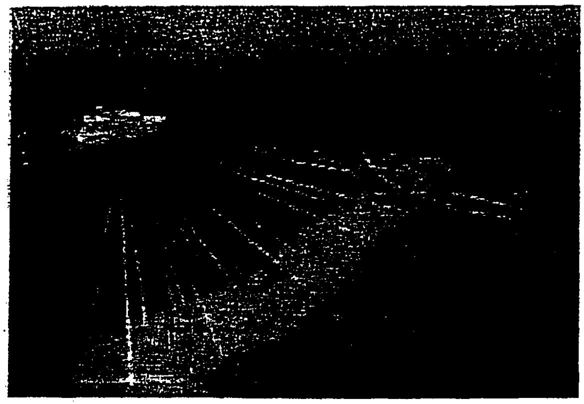

Figure 3. Underwater SONAR scan system.

Reference Datum System

The TWD-67 (Taiwan Datum 67/ 2°TM, Hu-tze-shan coordinate system) base on the GRS-67 reference ellipsoid has been used for several years in Taiwan for horizontal control. In the near future, the new TWD-97 base on the GRS-80 reference ellipsoid and the International Terrestrial Reference Frame (ITRF) will be used, so as to link up with the World Geodetic System 1984, based on the WGS 84 GPS datum.

Data Accuracy Study

Reliable data from both a bathymetric survey and an above-water topographic survey are necessary for creating a quality reservoir topographic map. The data processing procedure in the current research pays attention to the data screening procedure and cross-line check, the error analysis and error map building, and the internal reliability estimation of the reservoir topographic maps. It is highly recommended that tracking-route maps of the surveying vessel be included in the final report for inspection.

SUGGESTIONS FOR CREATING A RESERVOIR SEDIMENTATION SURVEY MANUAL SUITABLE FOR THE TAIWAN AREA

USBR's Reservoir Sedimentation Survey Manual Review

NCKU has carefully reviewed the Reservoir Sedimentation Survey Manual proposed by USBR in 2000, the IHO standards for hydrographic surveys, and the hydrographic survey manual of USACE. Following are some issues for discussion that were raised by this review:

1. The best time(s) of year for conducting reservoir sedimentation surveys in Taiwan
2. The frequency of reservoir surveys in Taiwan
3. The density of data to be collected during reservoir sedimentation surveys in Taiwan
4. Coping with GPS blockages and/or radio link interruptions
5. Correcting for the SONAR beam spreading effect (on steep canyon slopes)

6. Squat calibration and motion effect calibration methods
7. Quality control for reservoir sedimentation surveys in Taiwan
8. Methods of determining sediment volume suitable for use in Taiwanese reservoirs
9. Reasonable budget for a reservoir sedimentation survey in Taiwan
10. Necessary qualifications for survey crew members in Taiwan

The results from a discussion of these issues, together with the results from the questionnaire described below, will be used to produce a reservoir sedimentation survey manual suitable for Taiwan-area reservoirs.

Questionaire on Reservoir Sedimentation Surveys in Taiwan

NCKU sent out questionnaires about reservoir sedimentation surveys in Taiwan to 188 engineers and other specialists, and it received 102 responses, giving the following results:

- 95% of respondents agreed that a reservoir sedimentation survey manual for the Taiwan area is needed for quality control in field survey operations.
- 47% think that a multi-beam echo sounder should be used for sedimentation surveys.
- 49% think that the surveying range should include both the upstream and downstream portions of the reservoir surface area.
- 74% approve of licensing the survey personnel.

Suggestions for a Reservoir Sedimentation Survey Manual for the Taiwan Area

Based on responses to the questionnaire about reservoir sedimentation surveys in Taiwan and on a review of the existing hydrographic survey standards of IHO, USACE, and USBR, a research team from NCKU will make several suggestions for a reservoir sedimentation survey manual for the Taiwan area. Some of the suggestions are shown in table 1.

Table 1. Suggested standards for reservoir sedimentation surveys in Taiwan

Classification Accuracy	Class 1		Class 2	Class 3
	Hard bottoms	Soft bottoms		
Base control network				
GPS	RTK GPS	RTK GPS	DGPS	DGPS
Supplemental	<1/25000	<1/25000	1/25000	1/10000
Vertical	1st order	1st order	1st order	2nd order
Positioning (95% confidence level)	2 m	5 m	5 m	5 m
Sounding (single beam) (95% confidence level)				
Depth<5m	± 15 cm	± 15cm	± 30cm	± 30cm
5m<Depth<15m	± 30 cm	± 30cm	± 60cm	± 60cm
Depth>15m	± 30 cm	± 60cm	± 60cm	± 90cm
Bar check	>2/day	>2/day	2/day	1/day
Cross line check	Required	Required	Optional	Not reqd
Echo sounder frequency	>200 kHz	200 kHz	200 kHz	200 kHz
Boat speed	<5 knots	<5 knots	5~10 knots	<10 knots
Line spacing	<1 cm at plotted scale	<1 cm at plotted scale	1 cm at plotted scale	2 cm at plotted scale
Position-fix interval	<2.5 cm at plotted scale	<2.5 cm at plotted scale	2.5 cm at plotted scale	5 cm at plotted scale
HDOP criteria	<3	<3	<6	<6

CONCLUSION

DGPS positioning and single-beam soundings are still the major means of conducting reservoir bathymetric surveys in Taiwan. Using single-beam soundings together with underwater SONAR sidescan systems provides a means of inspecting bottom conditions in order to assess and adjust the line spacing during bathymetric surveys. RTK GPS positioning and multi-beam soundings in reservoir sedimentation surveys will be the main trend in the near future. GPS positioning supplemented by Laser terrestrial total station operation will be the solution for positioning during GPS blockages and/or during radio link interruptions, such as those that may occur at Kukuan Reservoir and other reservoirs located in the cliff territory of Taiwan. The Reservoir Sedimentation Survey Manual submitted by USBR to WRB in 1999 provided reference material and a good starting point for establishing the a Reservoir Sedimentation Survey Manual for Taiwan.

The Fourteenth AIT-TECO Water Resource Program
Annual Review Meeting Summary Report for Appendices 6 and 7

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I. INTRODUCTION

This report provides a summary of the activities for Appendix 6 and Appendix 7 to the Agreement performed by the U. S. Bureau of Reclamation (Reclamation) since the last annual review meeting held in Hsin Chu, Taiwan, on November 2, 2000. Reclamation technical assistance and training are provided in accordance with the Agreement between the American Institute in Taiwan (AIT) and the Taipei Economic and Cultural Office (TECO), and subsequent Appendices to the Agreement for specific program requirements. Seven Appendices to the Agreement have been issued which specify the scope of work to be performed by Reclamation. Currently, Reclamation technical activities, and cooperative studies between Taiwan and Reclamation are being conducted in accordance with Appendix 6 and Appendix 7 to the Agreement. Appendix 6 provides for technical assistance and consultation in the areas of water resources planning, design, and construction; while Appendix 7 provides for cooperative studies in sedimentation to be conducted jointly between Taiwan and Reclamation.

Since last year's review meeting, the Reclamation has continued to provide technical assistance and training for the development and management of water resources in Taiwan, at the request of the Water Conservancy Agency (WCA). Members of the Reclamation Technical Review Team visited Taiwan in November 2000, and June 2001, to provide technical review and assistance for the planning and design of several water resources projects. In August 2001, concurrent with this annual meeting two engineers from WCA attended training in Denver at an international seminar on dam safety.

In accordance with Appendix 7 to the Agreement the final year's work for cooperative sedimentation studies has continued. The GSTARS 3.0 model is in development and will be delivered by the end of the present calendar year. During 2001 there was delivery of 5 volumes of material (volumes 13 through 17).

The following Reclamation personnel have visited Taiwan to provide technical assistance, consultation, and training since the last review meeting in November 2000:

Chih Ted Yang (Reclamation Liaison Officer, and Sedimentation Study Leader)
Clarence Duster (Technical Review Team Leader)
Francisco Simões (Sedimentation Specialist)
Rick Ehat (Construction Specialist)
Mark McKeown (Engineering Geologist)
Blair Greimann (Sedimentation Specialist)
Peter Aberle (Consultant Grouting Specialist)

II. TECHNICAL ASSISTANCE ON WATER RESOURCES PROJECTS (APPENDIX 6 TO THE AGREEMENT)

A. Pao Shan II Reservoir Project

The Pao Shan II Reservoir Project, located in Shin Chu County near the existing Pao Shan Reservoir, includes a major embankment dam, spillway, outlet works, and a transbasin diversion to convey water into the reservoir. The project will provide much needed water supply to the Hsin Chu Area. Currently, the diversion tunnel construction is underway and the foundation excavation, grouting, and embankment construction contract has been awarded. The spillway and outlet works final designs are being prepared.

On October 30 and November 1, 2000, Reclamation Technical Review Team members Clarence Duster, Rick Ehat, and Mark McKeown performed the fourth technical review for the project. During the fourth review, the Technical Review Team provided comments and recommendations on the embankment dam design, foundation treatment requirements, construction materials and hydraulic structures designs. The fourth technical review results are presented in the report "Technical Review of Pao Shan II Project" dated February 2001.

On June 3-6, 2001, Reclamation Technical Review Team members Clarence Duster, Mark McKeown, Consultant Engineering Geologist, and Peter Aberle, Consultant Grouting Specialist, provided the fifth technical review of the Pao Shan II Project. During this review, the review team considered ongoing design and construction activities, changes to the embankment, foundation, and hydraulic structures designs since the last review, and the results of foundation grouting tests. The fifth technical review results, including comments and recommendations on the embankment and foundation designs, proposed grouting program, and hydraulic structures designs, are presented in the report "Technical Review of Pao Shan II Project" dated July 2001.

B. Hu Shan Reservoir Project

The planned Hu Shan Reservoir Project, located in west-central Taiwan near Dou Liao, is intended to meet water demands for the Yuen-Lin and Nan Tou areas with operation in conjunction with the Chi-Chi Weir Project. A major future water supply requirement will be the Yuen-Lin Offshore Industrial Complex. The project will consist of zoned earthfill embankment dams, spillway, outlet works, and transbasin diversion facilities from the Ching-Shui River.

Feasibility Designs for the project were completed in 1995, and the project has been permitted for future construction. Reclamation's Technical Review Team provided technical review of the feasibility designs in 1995. Currently, WCA is preparing to continue the necessary investigations and study for the Basic Designs. On June 8, Technical Review Team members Clarence Duster, Mark McKeown, Consultant Engineering Geologist, and Peter Aberle, Consultant Grouting Specialist visited the project site and provided assistance and consultation on proposed investigations and studies necessary for final designs. The results of the review are presented in the report "Technical Review of Hu Shan Reservoir Project" dated July 2001.

C. Nan Hua Dam Raise Project

Nan Hua Dam is an existing zoned earthfill structure with a maximum height of 87.5 m. The appurtenant structures include a large concrete overflow spillway, spillway chute, and stilling basin, outlet works, and transbasin diversion facilities. The dam and appurtenant structures were completed in 1993. The proposed Nan Hua Dam Raise Project includes raising the dam crest by 20 m, modifying the outlet works, and replacing the existing spillway crest structure. The dam raise project will increase the reservoir storage capacity to provide additional water supply to the Tainan and Kaoshiung areas.

Reclamation's Technical Review Team provided technical review and consultation for the original dam and appurtenant structures design and construction until their completion in 1993. In 1998, the review team provided technical assistance and review of the initial planning studies for the proposed reservoir enlargement project. On October 30-November 1, 2000, Reclamation Technical Review Team members Clarence Duster, Mark McKeown, and Rick Ehat provided technical review of the Nan Hua Dam Raise Feasibility Designs. The results of the review for the feasibility designs are presented in the report "Technical Review of Nan Hua Dam Raise Project" dated February 2001.

III. RESERVOIR SEDIMENTATION STUDIES (APPENDIX 7 TO THE AGREEMENT)

In accordance with Appendix No. 7 to the Agreement signed in August 1996, Reclamation has continued with the required work for the Reservoir Sedimentation Cooperative Studies. In April, Chih Ted Yang visited Taiwan. An interim progress report was then presented about the development of the GSTARS 2.1/3.0 models. The following volumes were also presented during that visit:

Volume 13 – User's Manual for GSTARS 2.1 (Generalized Stream Tube model for Alluvial River Simulation version 2.1), by Chih Ted Yang and Francisco J.M. Simões. This is the final version of volume 12, which was distributed in November 2000 during the GSTARS 2.1 training course in Taiwan.

Volume 14 – Sediment Transport Modeling – Combination of Theoretical Concepts and Practical Approach, by Chih Ted Yang.

Volume 15 – Sediment Transport Data, by Chih Ted Yang.

Volume 16 – Erosion and Sedimentation Aspects of Sustainable Development and Use of Reservoirs, by Chih Ted Yang.

Volume 17 – Reservoir Sedimentation Survey Manual, by Ronald L. Ferrari.

With the concurrence of the WRB, Reclamation will conduct the following activities until the end of 2001 or beginning of 2002:

1. Conclude the development of the GSTARS 3.0 computer model and preparation of the GSTARS 3.0 manual.
2. Reclamation will continue the effort of collecting reservoir sedimentation data for Taiwan's reference and use.
3. Conduct a course in Taiwan on the use of GSTARS 3.0.

IV. TRAINING

Since the last annual meeting, training has been provided to Taiwan's engineers under both Appendix 6 and Appendix 7 to the Agreement. On November 3-4, 2000, following the Annual Review Meeting in Hsin Chu, a two day training course on GSTARS 2.1 was conducted for Taiwan engineers by Chih Ted Yang, Francisco J. M. Simões, and Blair Greimann. During this training course, a preliminary version of GSTARS 2.1 was distributed, as well as the draft of the GSTARS 2.1 user's manual (volume 12). Concurrent with this annual meeting, two Taiwan engineers are attending the International Dam Safety Seminar in Denver.

V. SUMMARY

Since the last annual meeting in November 2001, Reclamation has continued to provide technical assistance, consultation, training in accordance with Appendix 6 and Appendix 7 to the Agreement. Reclamation's Technical Review Team for Appendix 6 activities provided assistance on the planning, design, and construction of the Pao Shan II Reservoir Project, Nan Hua Dam Raise Project, and the Hu Shan Reservoir Project during trips to Taiwan in October-November 2000, and June 2001. In addition, Cooperative Sedimentation Studies under Appendix 7 to the Agreement have continued with activities in the Fifth Year Scope of Work in due course. Training was provided in Taiwan on the GSTARS 2.1 computer model. Five volumes of progress reports were delivered. By the end of 2001 the development of the GSTARS 3.0 computer model will be concluded and delivered to the WRB with appropriate documentation. A training course on the use of GSTARS 3.0 will be conducted in Taiwan in the Spring of 2002.

The management and development of water resources continue to progress to meet the existing and future demands on Taiwan's available water supply. In addition the Cooperative Sedimentation Studies have served to advance the state-of-knowledge and practice for modeling and managing difficult sedimentation problems. Reclamation welcomes the opportunity to continue providing technical assistance and training for the AIT-TECO Water Resources Program, and to continue studies, such as the Cooperative Sedimentation Studies, that provide mutual benefits to both Taiwan and Reclamation. I would like to express Reclamation's sincere appreciation for the cooperation, hospitality, and friendship given us by Taiwan's water resources agencies, other agencies and organization, and the people of Taiwan.

2001 Annual Meeting Conclusions

1. The U.S. Bureau of Reclamation (USBR) and Taiwan's Water Conservancy Agency (WCA) and the Water Resources Bureau (WRB) of the Ministry of Economic Affairs agree to continue the existing Technical Assistance Agreement for another 5 years starting January 2002. The parties concerned agree to amend Appendix VI for Taiwan to reimburse the USBR based on its Technical Service Center's billable rates applicable to all internal and external customers. The scope of work under Appendix VI will be expanded to include river restoration.

2. USBR and WRB agree to extend the Appendix VII for another 5 years starting January 2002.

3. The extension of Appendix VII will emphasize continuation of application of GSTARS 3.0 for the reservoir sedimentation and the study of watershed erosion processes.

4. The 5-year study under Appendix VII will be divided into two stages. The first two years will establish work scope and approaches for watershed erosion processes. The remaining three years will develop methodology applicable to case studies.

5. For the first stage study under Appendix VII, WRB will exercise one or both of the following options.

    1. To provide US $10,000 per year for Dr. Chih Ted Yang, USBR, to provide preliminary consultation.

    2. To provide US $100,000 per year for USBR to develop rational erosion methodology and models. USBR shall provide detailed information regarding the physical consideration, mathematical and numerical formulation, and test cases study results.

The actual amount of funding from Taiwan will depend on the availability of funds in each year.

Jing-Jóin Lin Deputy Director General Water Resources Bureau Ministry of Economic Affairs	17, Aug. 2001 Date	Chih Ted Yang USBR Liaison Officer	Aug 17, 2001 Date