NBS BUILDING SCIENCE SERIES 100

Building To Resist The Effect Of Wind

VOLUME 1. Overview

RTMENT OF COMMERCE • NATIONAL BUREAU OF STANDARDS

NBS BUILDING SCIENCE SERIES 100-1

Building To Resist The Effect Of Wind

in five volumes

VOLUME 1: Overview

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PREFACE

This Overview is Volume 1 of a five-volume series.[1] The series describes the activities and accomplishments of a research project undertaken by the National Bureau of Standards for the Agency for International Development to develop improved design criteria for low-rise buildings to better resist extreme winds.

The purpose of the Overview is to provide the reader with a complete summary of this three and a half year project. It is presented for the benefit of the decision maker. The information in this volume is arranged in gradually increasing degrees of detail from an abstract, to an executive summary, to a detailed summary. Detailed technical information is presented in the four companion volumes noted below.

The first section, Introduction, contains three parts: goals and objectives of the project; background information (including selection of the three developing countries that participated in the project—the Philippines, Jamaica and Bangladesh); and a review of preparatory project activities. These activities included establishment of the Philippine Advisory Committee to coordinate local activities in that country, where the bulk of the wind measurement activities were performed.

Grouped under the heading Review of Project Activities, the reader will find a discussion of the two methods used to collect data during the course of this project. The first addresses the accomplishments of the wind measurement program through full-scale field tests and through wind-tunnel modeling. The second summarizes the process of collecting data through other means, including literature searches and workshops. This section also summarizes the contents of the four companion volumes. The essence of other related work carried out by individuals and institutions not connected with the NBS/AID project also is presented. Included are results of complementary studies performed by the Massachusetts Institute of Technology and the Carnegie-Mellon University.

The next section, Information Transfer, is devoted to a review of actions aimed at disseminating draft project findings to the users. Workshops, a 16-mm sound film and user-oriented materials are described.

The report concludes with two sections, Accomplishments and Needs and Recommendations.

The reader also will find appendices that provide supporting information. The first lists the participating organizations in the three participating countries and organizations from other countries who contributed to the outcome of the project. A second appendix references publications arranged under four categories: publications and articles developed during the course of the research; wind measurements and design loads; socio-economic factors and housing characteristics; and planning, design and construction technology.

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[1] The titles of the other four volumes are: Volume 2: *Estimation of Extreme Wind Speeds and Guide to the Determination of Wind Forces;* Volume 3: *A Guide for Improved Masonry and Timber Connections in Buildings;* Volume 4: *Forecasting the Economics of Housing Needs: A Methodological Guide;* and Volume 5: *Housing in Extreme Winds: Socio-economic and Architectural Considerations.*

ABSTRACT

This document presents the background, goals, procedures and results of a project to develop improved design criteria that can lead to low-rise buildings in developing countries that can better withstand the effects of extreme winds. The project stemmed from the belief that additional research on wind loads was needed to reduce loss of life and property, human suffering, disruption of productive capacity and costs of disaster relief. The three and a half year project began in early 1973. Results from the project include: a methodology for the estimation of extreme wind speeds; the development of wind tunnel modeling techniques; a heightened awareness of the wind problem and the need to guard against it; and the documentation of information in the areas of design wind speeds and pressure coefficients, economic forecasting, socio-economic and architectural concerns, and construction detailing practices. Also during the course of the project, a program began in the training of professionals and technicians in developing countries to carry out wind measurements and analyses. In addition, methods to ensure transfer of information to user groups were employed.

Project results are presented in five volumes. Volume 2 presents a methodology to estimate design wind speeds and a guide to the determination of wind forces. In Volume 3, a guide is presented for improved use of masonry connectors and timber fasteners. Volume 4 furnishes a methodology to estimate and forecast housing needs at a regional level. Socio-economic and architectural considerations applicable to the Philippines, Jamaica and Bangladesh are presented in Volume 5.

Key words: Codes and standards; disaster mitigation; housing; low-rise buildings; socio-economics; structural connections; technology transfer; wind loads.

Cover: Laborers erect a prefabricated wood test house, donated by the National Housing Corporation (Philippines), Quezon City.

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CONTRIBUTORS

The Center for Building Technology's project team wishes to acknowledge in particular six persons among the very many participants and contributors who all have made this project a success. They are:

Dr. Ernesto G. Tabujara, Professor of Civil Engineering at the University of Philippines and Chairman of the Philippine Advisory Committee (a committee of leading Philippine building professionals), who was responsible for coordinating the overall wind research activities based in the Philippines.

Dr. Roman L. Kintanar, Administrator of the Philippine Atmospheric, Geophysical and Astronomical Services Administration, who was responsible for all field data collection activities on six full-scale buildings. A significant portion of the project's results is based on the full-scale field studies.

Stephen A. Kliment, Architectural Consultant in New York City, synthesized a great amount of material supplied by the Center for Building Technology, including the three NBS/CBT progress reports prepared for the Agency for International Development, into this general overview report, Volume 1, and authored Volume 5, Housing in Extreme Winds.

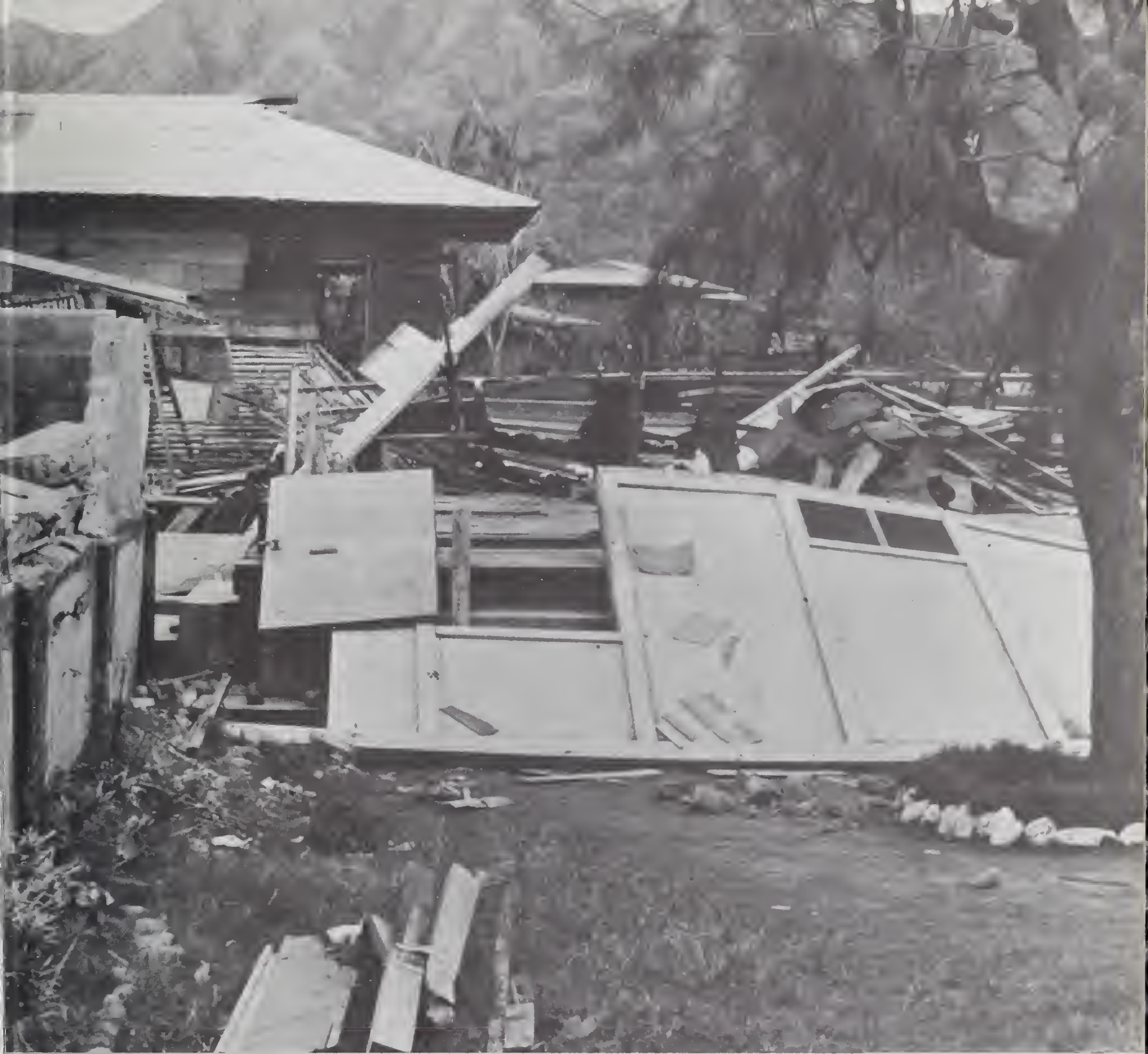
Dr. Jamilur R. Choudhury, Assistant Professor of Civil Engineering, Dacca University of Science and Technology. He represented Bangladesh and the Bay of Bengal countries in providing socio-economic, structural, architectural, and climatological data to the project and in transferring project results to his geographic area.

Alfrico D. Adams, of Douet, Brown, Adams and Partners, Consulting Engineers, Jamaica. He too provided the project with climatological, codes and standards, structural and socio-economic information and disseminated project results to the wind-prone countries of the Caribbean.

William H. Littlewood, the project monitor from the Office of Science and Technology, Agency for International Development. He recognized the need for this research and provided valuable guidance and support during the course of the project.

Many others provided valuable technical, logistical, and administrative support without which the project could not have been completed. These contributors are listed in Appendix A.

Facing Page: *High winds regularly cause damage to buildings such as this schoolhouse near Vigan, Philippines.*



EXECUTIVE SUMMARY

The effects of natural disasters are all too well known. Cost-effective improvements in building designs (such as improved roof-to-wall connections, roof geometry and structural bracing) tailored to the climates of developing countries can greatly reduce loss of human life and property, disruption of development, and the cost of disaster relief in those countries.

This research project originated from a recognition of the need for additional research to supplement limited existing data regarding the effects of wind on low-rise buildings, especially in developing countires. This research and the resultant development of design criteria and methodologies will reduce loss of life and property damage in the countries where the criteria are properly applied. As a result of this project, the National Bureau of Standards (NBS) developed and transferred improved knowledge on the performance of buildings under extreme wind conditions, with resulting benefits to communities world wide that are threatened by high winds.

The purpose of this Overview report is to summarize the efforts of this project and to serve as a guide to the other volumes of this publication and related articles and reports published during the course of the project (see page B-1).

BENEFITS

The activities and results of the project have produced the following benefits:

- Improved wind load design criteria have been developed to guide members of the building community in developing countries.
- Vital training of professionals and technicians has begun in developing countries for carrying out wind measurement and analysis.
- By means of workshops and other forms of information transfer, there is a growing sensitivity of the design profession to the need for improved ways to guard against the effects of extreme winds, and methods to improve building practices.
- Technical information has been tailored to the user's needs in developing countries.
- Essential but scattered documentation on good building practices has been identified for use by the building community.
- Interaction between members of the building community representing government, industry, professional and academic organizations was stimulated by this project in all participating countries.

FIELD TESTS AND WIND TUNNEL STUDIES

Three field test sites in the Philippines were selected for recording wind load data on buildings. The wind tunnel at the National Hydraulic Research Center, University of the Philippines, was used to carry out a series of test on models of full-scale test buildings. These model studies were used in the planning of full-scale studies and the interpretation of test results. NBS project staff also arranged for a series of comprehensive wind tunnel tests to be carried out at the Virginia Polytechnic Institute and State University where a more accurate simulation of atmospheric surface flows was established. The results of these and other studies are discussed in detail in the NBS Interagency Report NBSIR 75-790, reference 8, page B-1.

ADDITIONAL PROJECT INVESTIGATIONS

To complement the information collected from full-scale tests and wind tunnel studies, NBS staff and consultants developed special information in key subject areas. This information is in the form of four companion volumes to this Overview. These companion volumes are further described in section 2 of this Overview.

Volume 2 consists of two reports. The first, *Estimation of Extreme Wind Speeds—Application to the Philippines*, reviews probabilistic techniques for the analysis of existing data and the selection of design wind speeds. It also states that design speeds currently used in the Philippines can be reduced in some areas but should be increased in others. The techniques may be used to perform similar analyses in other countries. Simplified procedures for the calculation of wind pressures acting on building surfaces were developed. These procedures and associated design criteria provide building professionals with more reliable design loads. This information is presented in the second report, *A Guide to the Determination of Wind Forces*. The report describes the basics of wind flow around buildings and the pressures created by these flows on building surfaces. The data can form the basis for wind load design standards in developing countries.

Volume 3 of this series, *A Guide for Improved Masonry and Timber Connections in Buildings*, presents recommendations for good construction practices and details, especially for countries experiencing extreme winds. The report serves as a reference for improving building practices.

The project also produced a method to allow a country's planners, economists, public officials, and other decision makers to assess housing needs for up to 20 years into the future. The method is described in Volume 4 of the series, *Forecasting the Economics of Housing Needs: A Methodological Guide.*

Information on the cultural and socio-economic factors that affect building practices was developed as Volume 5, *Housing in Extreme Winds: Socio-economic and Architectural Considerations.* It shows how strong, inexpensive, locally available building materials can be integrated with good building design. The report is user-oriented and addresses the Philippines, Jamaica and Bangladesh. Materials that are cheap, strong and locally available are recommended, and several innovative methods of construction are discussed.

TECHNOLOGY TRANSFER

Project results were discussed at two regional conferences; one in Manila, Philippines (May 1975) and the other in Kingston, Jamaica (November 1975). These conferences provided linkages for transferring project results to the building community composed of government agencies, private developers, design professionals, regulatory officials, as well as university staff from Asian and Caribbean wind-prone countries.

Summaries of the workshops are discussed later in this Overview and are described in further detail in NBS Interagency Reports 74-567 and 75-790 cited below. To stimulate the general public to improve their buildings to better resist extreme winds, user-oriented material has been developed which contains concise and graphic descriptions of technological issues, and research findings. One such item titled, *43 Rules: How Houses Can Better Resist High Winds*, has been published as an NBS Interagency Report and could be translated and modified by the local AID missions and/or appropriate in-country housing organizations to meet each country's unique requirements.

Another user-oriented product is an 18 minute, 16 mm movie summarizing the project and its results. Starting with the destructive effects of winds on buildings, it moves to the NBS field-testing activities, the wind tunnel-testing program and the project's outputs. Additional information about the movie may be found in section 3.3 of this volume.

OTHER PUBLICATIONS

Several important vehicles communicating the results of this project have been made available to the public. Chief among these is a series of three NBS Interagency Reports (NBSIR) which describe in detail the progress of the project through Fiscal Years 1973, 1974 and 1975. Each report includes not only a progress summary for that year but also the full texts of associated papers, reports, minutes of meetings and workshop agendas developed during the fiscal year. They are cited as references 1, 2 and 8, page B-1.

In addition to these documents, the proceedings of a special 1973 workshop in Manila which identified the state-of-the-art of wind technology in developing countries was published as NBS Building Science Series 56, *Development of Improved Design Criteria to Better Resist the Effects of Extreme Winds for Low-Rise Buildings in Developing Countries.* This report is identified as reference 3, page B-1.

NEEDS AND RECOMMENDATIONS

Several recommendations evolved from the project. They include the need for comprehensive post-disaster surveys and prompt reporting of findings; further improvement of transfer of user-oriented information to local craftsmen; incorporation of project test results in the codes and standards of developing countries; and recognition by US standards-generating committees of the findings of this project as they consider the development of new or revised standards for wind loading.

Facing Page: *A typical low-cost village home in Daet, Philippines.*

1. INTRODUCTION

The US Agency for International Development (AID) and the National Bureau of Standards (NBS) recognized a need for design criteria that would improve the ability of low-rise buildings in developing countries to withstand the effects of extreme winds. By 1976, over three years after it began, the project that grew out of this recognition drew to a close. Among its accomplishments were the development of improved design criteria for wind loading; a methodology for the estimation of extreme wind speeds; a greater awareness of the urgent need for better ways to guard against the ravages of extreme winds; the productive interaction between members of the building community in the three developing countries involved with the project; and the documentation of essential information in the areas of design wind speeds and pressure coefficients, economic forecasting, socio-economic and architectural concerns, and construction detailing practices.

The project also inaugurated the training of professionals and technicians in developing countries to carry out wind measurement and data analysis. In addition, the project set out deliberately to create linkages for transfer to, and information use by members of the building community, including the general public.

The following text presents the goals and objectives of this project, reviews the procedures used to carry out the assignments, and identifies benefits and future needs.

1.1 GOALS AND OBJECTIVES

The project's primary goal was to reduce loss of life and property, human suffering, disruption of productive capacity, and expenditures for disaster relief resulting from the effects of extreme winds on low-rise buildings.

The objectives for carrying out this goal were: 1) to learn more about the effects of high winds on low-rise buidings; 2) to develop improved siting, design, and construction information which would improve the resistance of buildings to extreme winds and be culturally acceptable to the general public; 3) to provide training to local professionals and technicians in performing wind-load measurement and analysis and wind-tunnel testing; and 4) to provide a large-scale transfer of technology to promote use of these improvements in design and construction, as well as new climatological, sociological and economic findings.

1.2 BACKGROUND

Wind loading of tall buildings has recieved considerable attention during the past ten years, but little parallel work has been devoted to buildings less than 10 m high. Post-disaster investigations of wind damage suggest that design pressure coefficients contained in most current codes and standards do not adequately reflect wind characteristics near the ground, nor the true nature of pressure fluctuations on low-rise buildings. Highly localized wind pressures on buildings tend to be underestimated, whereas overall pressures tend to be overestimated. This is in agreement with the results of full-scale tests carried out during this program.

No less important to understanding wind loads on buildings is the selection of appropriate design wind speeds in areas having a high frequency of tropical storms. By taking into account local storm frequencies and terrain effects, design speeds can be specified such that the risk of wind damage to properly designed and constructed buildings is acceptable. This will allow the building designer to specify more realistic design loads and should result in better performance of buildings during their expected life.

High-level decision makers in the Philippines, Bangladesh and Jamaica took part in the study. The individuals participating in this project were selected on the basis of their potential for carrying out this research effort and their ability to transfer research results, including their implementation, to their respective geographic areas.

The project was centered in the Philippines. There, Luzon Island experiences the highest annual frequency of tropical storms[2] in the world, and 50 percent of the Philippine population lives within this area. Because of the area's climatology and the variety of problems created by the rapidly spiraling population (36.7 million people estimated by the 1970 census, with an annual growth rate of three percent), loss of life and property can be expected to increase in the years ahead. Post-disaster reports on the impact of typhoons indicate millions of dollars of property are damaged annually, and hundreds of lives lost due to these typhoons. In 1970, the Philippines experienced four typhoons; these caused over 1,000 deaths and $45 million damage to property, including, the loss of 9,000 public school classrooms. Over 300,000 school children were affected by the storms. The Philippines therefore is a natural laboratory to measure wind loads on buildings.

The other areas selected also are heavily populated and experienced extreme winds; they include the Bay of Bengal countries and the northern Caribbean Islands (see fig. 1). Stars on figure 1 denote countries directly participating in this project.

1.3 PREPARATORY ACTIVITIES

Early in the project the NBS project team traveled to seven developing and developed nations to introduce the study to members of the local building community and to assess the ability of building research organizations in developing countries to carry out research into the effects of wind on buildings.

After the Philippines had been selected as the site for the principal measurement effort the need arose to establish a board of leading officials in the Philippines to advise and participate in the project. This board, called the Philippine Advisory Committee (PAC), consists of over 20 leading individuals representing governmental agencies, an academic institution, housing authorities, building research laboratories, financial lending institutions, professional societies plus the AID Mission to the Philippines and the NBS. Representatives of CARE Inc. in Bangladesh and building consultants from Jamaica and Bangladesh also took part in PAC's discussions. PAC has met regularly during the project, and is expected to continue to meet, to continue the data collection and analysis program and to further integrate the project's results into that nation's everyday planning, design

[2] Wind speeds greater than 18 m/s.

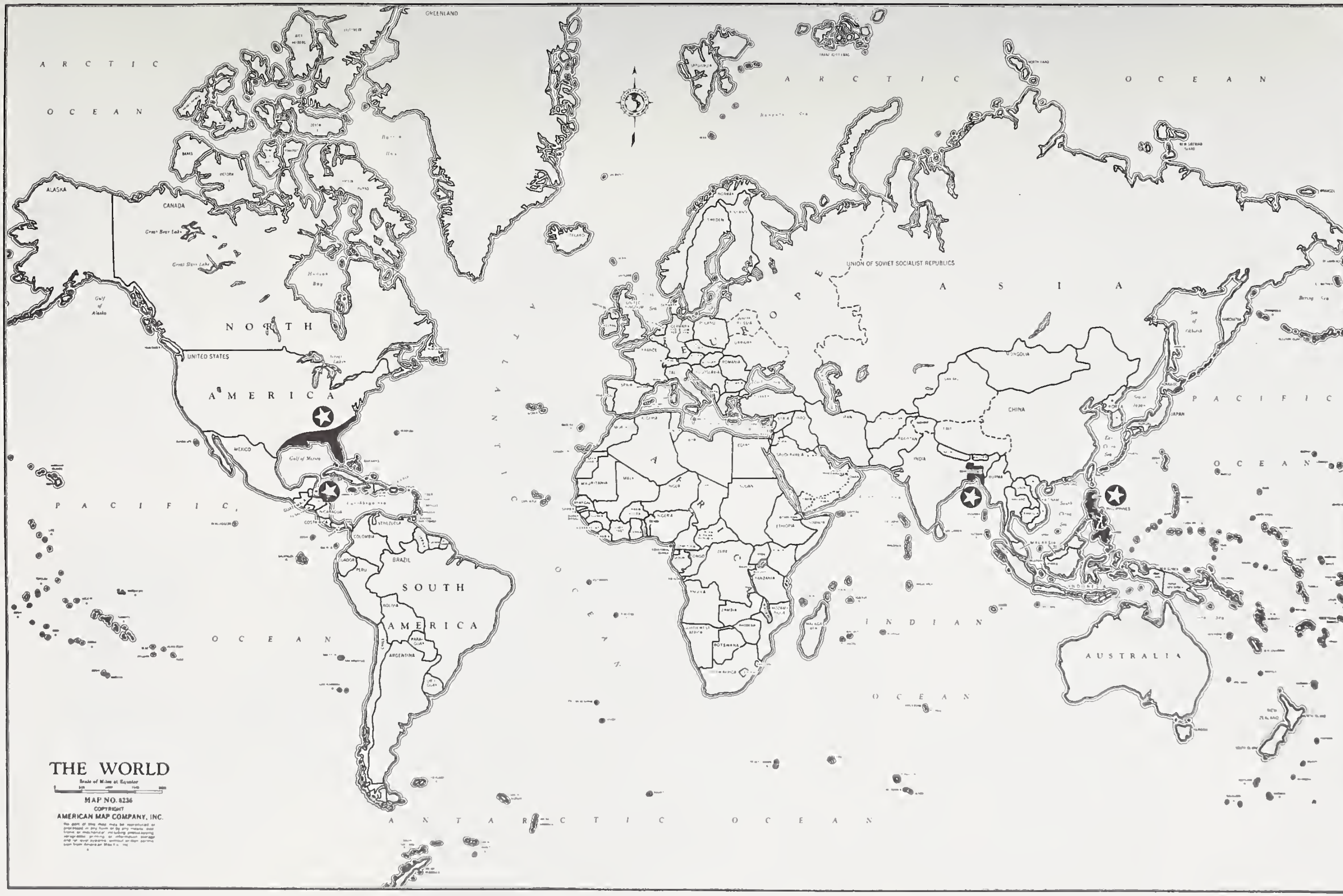


FIGURE 1 GEOGRAPHIC LOCATIONS OF WIND-PRONE COUNTRIES PARTICIPATING IN THE STUDY.

and construction practices. Similar advisory and support arrangements were set up with the building communities in Bangladesh and Jamaica.

Early in the project, sites were identified by PAC for conducting full-scale tests. The three sites chosen were weather stations operated by the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) at Quezon City, Daet and Laoag City (see fig. 2). Site selection criteria included: frequency of extreme winds, easy access, reliable commercial power, type of wind exposure and site security. Arrangements with individual representatives of PAC were made to build test houses at the sites and to instrument these for measuring and recording wind speed and pressure.

Full-scale field tests were supplemented by wind tunnel model studies at the University of the Philippines' National Hydraulic Research Center. An aeronautical tunnel was modified to make it suitable for simulating atmospheric surface flows. Models of the full-scale buildings were built by local technicians and tested in the tunnel. These model tests were designed to aid in the positioning of instrumentation on the full-scale test houses and interpretation of field test results.

Finally, since research findings are valuable only if the technical, economic and cultural environment is right for their acceptance, NBS retained consultants from Bangladesh, Jamaica and the U.S. to develop information on the socio-economic features of the three countries being studied, on the economic aspects of predicting housing need, and on recommended siting, design and construction practices.

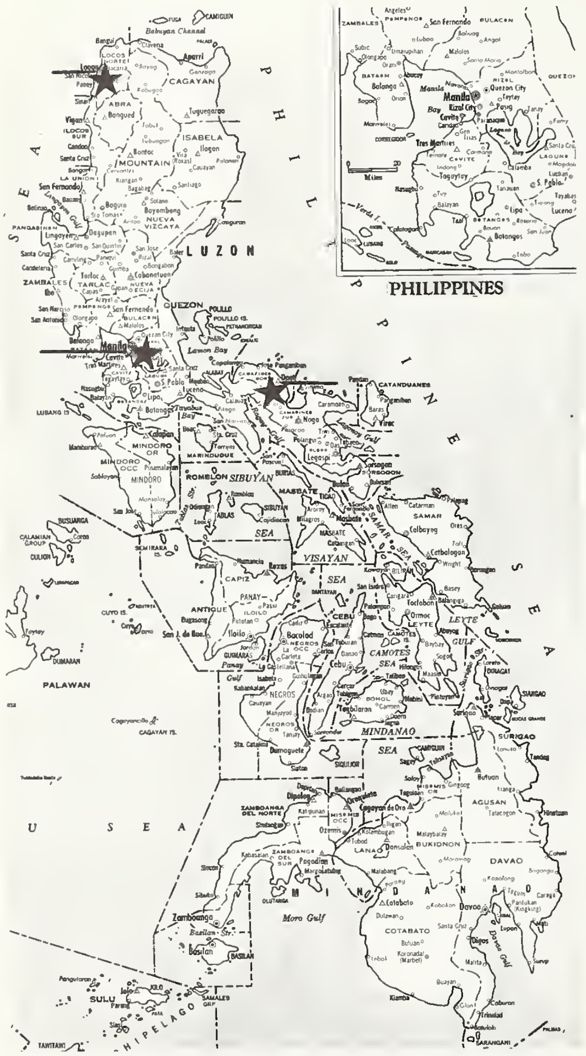


FIGURE 2 FIELD TEST SITES.

Facing Page: These houses have been instrumented with pressure sensors (round disks) to help understand the wind loads they experience.

2. REVIEW OF PROJECT ACTIVITIES

2.1 DEVELOPMENT OF INFORMATION THROUGH MEASUREMENT

The bulk of the research centered around field studies (direct measurement of wind loads on six low-rise buildings at the three separate sites in the Philippines) and wind tunnel studies (scale models of the field test buildings and models of other typical dwelling geometries). The chief purpose of these studies was to develop design pressure coefficients for low-rise buildings.

2.1.1 Full-Scale Field Tests

Single-story test houses were built at the Quezon City site (three houses) and at the Laoag City site (two houses). An existing single-story weather bureau building was used at the Daet site.

The houses were instrumented with pressure sensors and each field site was equipped with a propeller-vane anemometer to measure wind speed and direction and a data acquisition system developed at NBS. The data acquisition equipment used in the full-scale test program consisted of five basic systems; 1) the sensors or transducers, 2) a logic system, 3) a signal conditioner, 4) a recorder, and 5) a power supply. These systems were designed to continuously monitor wind speed and to initiate a recording sequence when the speed exceeded a preset level (about 20 m/s). The system then would record speed and pressure data for approximately 20 minutes and then enter a 30-minute "hold" period. The total recording time available on a reel of tape was approximately six hours. Thus, the total time period between changes in tape reels (six hours of recording plus six hours of "hold" periods during continuous high wind conditions) was over 12 hours; this was enough tape for most typhoon passages.

Wind speed and direction were measured by a propeller-vane anemometer mounted on a 10 m mast located far enough from the test buildings to register undisturbed wind speeds. The recording sections consisted of a 14-track analog tape unit with reels containing 1100 m of magnetic tape.

To ensure uninterrupted power in a storm, all three sites were equipped with a back-up system of batteries. Whenever commercial power is interrupted, the batteries automatically pick up the load for about eight hours of continuous operation.

Since typhoon winds can come from any direction, it is difficult to determine a "best" configuration or array of pressure transducers. Because roof structures are the most susceptible to wind damage, they were allocated the greatest number of transducers. Extreme pressures acting along ridge lines, eaves and roof corners were of interest, as were the average uplift presures acting on the overall roof area. Pressure transducers were arranged differently on each test building to provide a wider range of transducer combinations for the assessment of localized and overall pressure fluctuations. Transducers also were installed inside the building to measure internal pressures, as these pressures strongly influence the net roof up lift loads

Over the three years of the study, approximately forty hours of recordings were obtained and processed.

2.1.2 Wind Tunnel Studies

While full-scale tests provide valuable information on the nature of wind forces and the response of buildings to these forces, they generally do not allow detailed and systematic study of the various parameters involved. It is usually necessary to resort to modeling techniques to provide sufficient data on which to base design criteria, using the full-scale results to check the validity of the model. For this reason, and also to provide a facility to meet future research needs, the wind tunnel at the National Hydraulic Research Center (NHRC), University of the Philippines, was modified so that the lower portion of the atmospheric boundary layer could be modeled. Techniques used to establish an acceptable degree of similitude were developed for this particular application in a similar wind tunnel at Colorado State University and involved the installation of tapered spires at the entrance to the test section, followed by surface roughness elements placed on the floor of the tunnel and extending downstream to the location of the building model. Details of the modeling technique are described in *Simulation of Atmospheric Flows in Short Wind Tunnel Test Sections*, which may be found in reference 2, page B-1.

The NHRC wind tunnel has a test section 1.2 m square and 3.7 m long. Maximum air speed with a clear test section is approximately 30 m/s. While a tunnel with a larger test section would have simplified the modeling problem, surface pressures measured on a 1:80 scale model of Test House No. 1 at Quezon City (see fig. 3) correlated well with the full-scale measurements. This model, installed on a turntable at the downstream end of the test section, is shown in figure 4. In addition to providing guidance for the optimum location of pressure transducers in the full-scale studies and aiding in the interpretation of records obtained from these studies, the NHRC tunnel was also used to study a model of a Bayanihan School Building. A large number of these buildings were constructed with AID funding following the typhoons of 1970 and the objective of this wind tunnel study was to evaluate the loads used in the original design and refine these loads for future construction. A typical Bayanihan School Building is shown in figure 5 and results of the study are presented in a report, *Wind Tunnel Studies of RP-US Bayanihan Permanent School Building* (see reference 17, page B-1).

The NBS initiated a series of comprehensive wind tunnel tests at the Virginia Polytechnic Institute and State University (VPI and SU) where a larger test section was available and the atmospheric boundary layer had previously been modeled successfully. The tests covered 32 combinations of roof slope, height-to-width ratio, length-to-width ratio and size of roof overhang. Detailed discussion of the test results is reported in the VPI and SU report, *Wind Tunnel Model Investigation for Basic Dwelling Geometries* (see reference 12, B-1). The influence of roof slope on wind loads for the models tested is summarized below.

Zero-degree roof slope. Peak pressures occur at points close to the upstream roof edge with the wind normal to the edge and deviating ±60 degrees from the normal direction. Towards the center of the roof the mag-

FIGURE 3 TWO TEST HOUSES AT QUEZON CITY SITE.

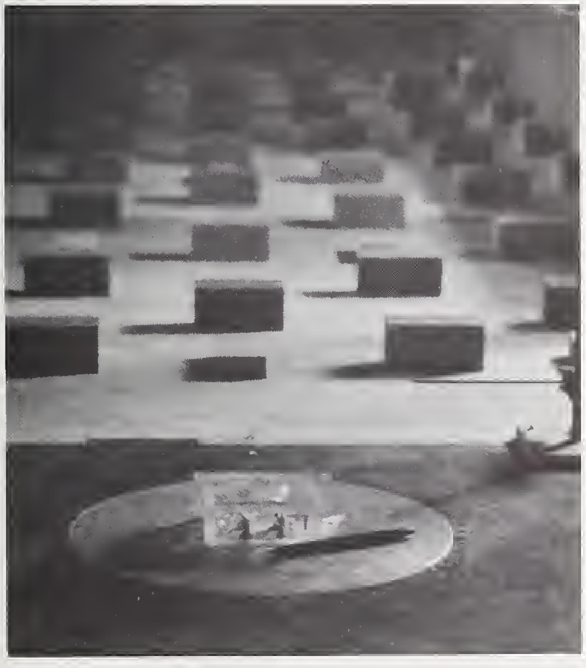


FIGURE 4 PHOTOGRAPH OF SCALE MODEL OF FIELD TEST HOUSE INSTALLED IN UNIVERSITY OF PHILIPPINES WIND TUNNEL.

FIGURE 5 BAYANIHAN SCHOOL BUILDING.

nitude of the peak pressures decrease and the sector in which these peak pressures occur becomes smaller. The presence or the absence of roof overhangs does not seem to influence the magnitude of the peak pressures or the sector in which they occur. The same is true for the length-width ratio; this variable does not seem to affect the peak pressures.

Ten-degree roof slope. Again, the peak pressures occur at the upstream edges of the roofs and decrease in magnitude towards the middle of the roof. The presence of the roof ridge does not show any effect on pressures near the ridge. The maximum pressures occur along the upstream sloping edges of the roofs with the wind direction parallel to the roof ridge and in a sector deviating ±50 degrees from this direction. No significant effects due to the presence of roof overhangs can be detected except for the case with winds parallel to the roof ridge. The magnitudes of the peak pressures along the sloping upstream edge of the roof are smaller than in the case where no overhangs are present. There is clear evidence that the larger length-width ratio decreases the magnitude of the peak pressures.

Twenty-degree roof slope. For this geometry, the presence of the roof ridge becomes important. Extremely large negative pressures do occur on the leeward side of the ridge with the wind direction making an angle of 45 degrees with the roof ridge. The overhangs and the length-width ratio do not seem to have any effect on the magnitude of the peak pressures. Winds parallel to the roof ridge create low peak pressures at the leading and sloping edges of the roof. In general, the magnitudes of the pressures towards the center of each roof slope are larger than previously experienced with winds normal to the ridge, both on the windward and leeward side.

Thirty-degree roof slope. The peak pressures occur at the leading edge of the roof with the wind parallel to the roof ridge in a sector of approximately 50 degrees on either side. In addition, large negative pressures are encountered on the leeward side of the roof, with the wind direction making an angle of approximately 45 degrees with the roof ridge. However, these peak negative pressures are not as low as those encountered at the same location and with the same wind direction for twenty-degree roof slopes. In cases where the winds are normal to the roof ridge, the upstream (horizontal) edge of the roof is not exposed to the large negative pressures encountered with flatter roof slopes. The largest negative pressures are encountered over the entire leeward roof area with the wind direction making an angle of approximately forty-five degrees with the roof ridge. Overhangs and length-width ratio do not seem to have any appreciable effect on the peak pressures in this case. These studies indicated that additional research is needed for roof slopes near 10 degrees.

In addition to the wind tunnel investigation of basic dwelling geometries just described, studies were also conducted at the test site in Quezon City. Results indicated that there was no unusual sensitivity of the building geometry to extreme winds. These studies, were published as, *Wind Tunnel Investigation of CARE, Inc. Single-Family Dwelling,* (see reference 14, page B-1).

2.2 COLLECTION OF COMPLEMENTARY DATA

Throughout the project the systematic use of literature searches, workshop/conferences and consultants yielded comprehensive information on listings of printed resources, socio-economic data, and guidelines for siting, design and construction detailing practices.

2.2.1 Literature Search

Reports concerned with wind effects and building technology were collected from the NBS, the Department of State, AID, the National Oceanic and Atmospheric Administration, the Forest Products Laboratory, the Portland Cement Association, the National Technical Information Service and various US and overseas universities. Additional documents came from the Building Research Establishment in the United Kingdom through a collaborative research program with the NBS on wind loads on buildings. Copies of approximately 75 documents collected in this search were transferred to the PAC and the bibliography was sent to other participating developing countries. A list of all these documents appears as Appendix C of NBSIR 74-567 (reference 2, page B-1).

2.2.2 Workshop/Conferences

One workshop and two conferences were held during the course of the project, two in the Philippines and one in Jamaica. These served to elicit information on wind design, construction and socio-economic experiences; the conferences served as a key vehicle for the timely dissemination of project findings.

The workshop was held in Manila November 14-17, 1973. Entitled "An International Workshop on Effects of Extreme Winds," it addressed the state-of-the-art in mitigating building damages caused by winds. Four themes were discussed: climatology and aerodynamics; structural engineering; socio-economic and architectural considerations; and codes and standards.

The workshop, attended by 140 professionals from Jamaica, Bangladesh, the United Kingdom, the Philippines and the United States, identified defects in data gathering procedures, identified gaps in wind loading data and the building process, developed recommendations to correct these defects and suggested improvements for good building practices. The proceedings of the workshop were published as NBS Building Science Series 56 (see reference 3, page B-1).

The first of two regional conferences was held in Manila, on May 16-17, 1975. The second was held in Kingston, Jamaica, on November 6-7, 1975. The purpose of these conferences was to provide project results to the professional building community in wind-prone developing countries. This was done to avoid long lag-time until publication of results (about 1 1/2 years in this case), thus allowing the countries to begin to implement results as quickly as possible. At the same time, it gave the NBS team a chance to receive technical feedback as to the relevance of project research to date. This feedback was of assistance in subsequent data collection and analysis and guided the preparation of final technical reports. The conference programs are contained in reference 8, page B-1.

2.2.3 Summaries of Companion Volumes

The other volumes in this Building Science Series deal with design wind speeds and pressure coefficients; timber fasteners and masonry connectors leading to improved construction practices; forecasting housing needs; and socio-economic and architectural implications. Each is published separately. A summary of each is presented below.

Volume 2, *Estimation of Extreme Wind Speeds and Guide to the Determination of Wind Forces,* contains two related reports. The first report, *Estimation of Extreme Wind Speeds—Application to the Philippines,* concludes that design speeds currently used in parts of Mindanao can be reduced, whereas those in use for Northern Luzon and certain coastal exposures should be increased. The report also focuses on problems of estimating basic wind speeds for very long mean recurrence intervals in tropical storm areas where wind records are often incomplete and many typhoons pass without being recorded.

The report contains a comprehensive review of probabilistic techniques for analyzing extreme wind speeds. It also provides for the correction of annual extreme speeds for the type of instrumentation used, averaging time, height above ground, and type of exposure so that homogeneous data sets can be established. The two types of extreme value distributions in common use (Fisher-Tippett Type I and Type II) are then applied to the annual extremes for several Philippine stations using an NBS developed computer program. The author then compares the results of the analysis with design speeds currently specified in the National Structural Code of the Philippines.

The second report, *A Guide to the Determination of Wind Forces*, presents a method for calculating wind pressures acting on building surfaces. This report also describes the basics of wind flow around buildings and the pressures created by these flows on building surfaces. Effects of such features as roof slope, roof overhang, and building openings are discussed. The report refers to material covered in its companion report and assumes that the basic wind speed either is known or can be calculated by the designer. A procedure for determining the design speed is presented. It takes into account general terrain roughness, local topographical features, height of building, expected life of building, and risk of exceeding design loads. Once the design speed has been obtained, the mean dynamic pressure may be calulated and pressures acting on walls, roofs, and internal protions of buildings may be determined by use of appropriate pressure coefficients presented in the report. Corrections then can be applied to the calculated pressure to account for terrain roughness and height of building. Finally, the pressures are multiplied by the appropriate surface areas to obtain wind forces. The steps required to calculate pressures and total drag and uplift forces are summarized. The paper concludes with worked examples. These improved design criteria provide building professionals with more reliable design loads and are intended as the basis for wind load design standards in developing countries.

Volume 3 in this series, *A Guide for Improved Masonry and Timber Connections in Buildings*, contains material on recommended construction practices. The report discusses three basic structural systems: pole type, masonry bearing wall and timber. Examples of wind damage are included through use of text and photographs. Cases in which inadequate fasteners and improper design contributed to roof damage or lift off followed by collapse of the entire structure are described.

The authors, from NBS and Forest Products Laboratory, evaluate current construction practices in the tropics, and discuss local building products and standards compliance with the aid of photographs of buildings during various stages of construction. They also present current building practice in the United States, along with illustrations of various types of connectors and fasteners. While many of these connectors and fasteners are not currently used in developing countries, they serve as a reference for improving local practices and customs.

Volume 4, *Forecasting the Economics of Housing Needs: A Methodological Guide*, presents a method for decision makers in government and the private housing industry to determine the size of a region's unmet housing needs. This is an important first step in planning and enacting public policies and programs designed to improve the size, condition and quality of a nation's housing inventory. The procedure makes use of readily available data such as family income, housing expenditure and the established regional poverty line. Procedures are developed to compare the costs with the potential income redistribution effects of meeting the housing need shortfall. They have been designed to be flexible and adaptable to situations in which housing and demographic data may be sparse. The calculation of current housing needs is divided into 11 steps or tasks. These in turn are grouped into four major areas of investigation—description of housing inventory, determination of the housing standard, determination of the need (or "shortfall matrix") and calculation of the cost of meeting the housing needs. An extended example is included.

Volume 5, *Housing in Extreme Winds: Socio-economic and Architectural Considerations*, reviews the importance of cultural acceptance of planning, design and construction improvements that differ from traditional practices in developing countries. The report focuses on the Philippines, Jamaica and Bangladesh and pinpoints typical socio-economic conditions that planners should take into account. These conditions include: strong respect for traditional materials and methods of house construction and suspicion of innovative forms and approaches; a rising proportion of urban poor who live in squatter settlements; a still high proportion of rural residents, remote both from new building concepts and from post-typhoon/hurricane relief programs; a very high ratio of citizens (in a range from 60 to 72 percent, depending on the country) whose incomes are at a level where they cannot afford housing of any kind—either on the open market or government-subsidized; and a chronic shortage of capital funds to stimulate or support a national program for the construction of wind-resistant housing. The importance of land from a social standpoint is stressed. The report cites benefits of the "sites and services" concept whereby low income persons are provided (through gift, loan or lease) a site equipped with water supply, sewerage and electricity, but must erect and maintain a house upon it.

Architecturally, recommendations include placement of buildings to exploit the beneficial effects of terrain, and adherence to principles of good practice in the configuration of roofs, walls, overhangs and openings. These recommendations are shown in the report by drawings.

Materials that are cheap, strong and locally available are recommended, and several innovative methods of construction are mentioned. They include stabilized or strengthened soil, and indigenous fibers and grasses for reinforcing concrete, adobe and brick. Plastics have been produced using local and imported raw materials. If used for shelter, plastics could result in an excellent low-cost house once the housing configurations become more familiar to the population. At first, plastics may be used for community service buildings such as clinics and schools.

2.2.4 Summaries of Other Related Reports

At the mid-point of the project, additional information was collected from the December 25, 1974, cyclone which struck Darwin, Australia, and almost totally destroyed the city's residential areas. Due to the widespread use of corrugated galvanized iron sheet and light frame construction, the behavior of housing in Darwin will have a definite bearing on the development of design criteria for housing in other tropical regions of the world, especially those with frequent intense storms. NBS was invited to take part in post-disaster studies of Darwin. Close liaison developed and continues with Australian research establishments as they carry out follow-on projects related to Darwin. Some of these findings and recommendations such as improved fasteners for corrugated iron roofing sheets should work well in other countries which are prone to tropical storms (see reference 21, page B-4).

Dr. Jamilur R. Choudhury (Bangladesh) and A. D. Adams (Jamaica) were retained by NBS to prepare background reports on the wind conditions, socio-economic profile and construction circumstances in their respective countries and geographic regions.

Dr. J. R. Choudhury prepared a report entitled *Low-rise, Low-cost Housing and Extreme Wind-related Problems in Bangladesh.* He sees a need for six million new rural houses over the next 10 years. The author points to the following projections and facts: enormous expected rise in population in his country over the next decade, to produce a high population density; a high frequency of disastrous typhoons; and negligible natural resources. In spite of an influx of rural families to the large cities raising urban populations by as much as 50 percent, the number of houses has remained about the same. Furthermore, by mid-1975, the high cost of building materials had brought new private building construction to a virtual standstill.

Reliable wind speed records are lacking and weather stations are poorly equipped. The report suggests wind speeds for return periods of 20, 50 and 100 years at eight stations, but the author calls for a more thorough analysis of existing wind data before using the values for building design.

The author also reports briefly on housing and wind conditions in India, Burma and Sri Lanka. Existing data suggests lower design wind speeds for these three countries except for the West Bengal, Orissa and Madras coasts of India where speeds compare with those for Bangladesh. This report appeared as Appendix B of the NBSIR 75-790 (see reference 8, page B-1). It may be ordered seperately from the National Technical Information Service as PB 256-771 (see page B-1 for the NTIS address).

Mr. A. D. Adams, a Jamaican consulting engineer prepared, *Low-Cost Housing and Extreme Wind-Related Problems in Jamaica and the Northern Caribbean Islands.* This two-part report identifies low-cost housing trends and their design problems in the region. It notes the influence of socio-economic factors on housing patterns and presents an analysis of housing needs over the next ten years.

Between 1975 and 1985, the author sees an average annual need of about 15,000 units, two-thirds of them for use by new households, the rest for replacement. These estimates are based on an anticipated population increase of 400,000 over the decade.

The private sector provides housing for middle and upper income groups. Only a small part of the government's housing effort has been directed at the lowest income groups. To relieve these pressures, the Ministry of Housing in 1972 began its Sites and Services Project aimed at providing 6,000 serviced lots in three years. The objective is to encourage self-help projects for prospective home owners who are largely unemployed.

The author presents extreme winds and wind damage statistics. Included are maximum gust speeds for return periods of 10, 20, 25, 50 and 100 years. The author notes that a basic wind speed of 54 m/s has been recommended for design purposes in the region. This is a three-second gust speed at 10 m above ground for a return period of 50 years.

In his conclusion, the author offers several solutions for mitigating losses due to high winds. These include: 1) an adequate hurricane warning system; 2) strict adherence to accepted structural standards accompanied by tight inspection during construction; 3) simple instructions set out in a "Manual of Accepted Practice" to guide engineers, architects, developers, etc. as a supplement to building codes; 4) a professional engineering registration law for those nations without one; and 5) special emphasis on the major problem area of roof fastenings and anchoring provisions. Accurate data on design forces, or recommended standard details, would ensure both economy and a consistent and adequate standard of safety. The complete two-part report appears in reference 2, page B-1.

The paper, *Socio-Economic and Architectural Considerations in Housing,* was delivered at the November 14-17, 1973 Manila workshop by Geronimo V. Manahan and Dr. Josefina M. Ramos. The authors note that 85 percent of the potential wage earners in the Philippines have basic economic problems—no jobs or not enough income. This has led to malnutrition, ill health and environmental health hazards. Only 14 percent of urban families could afford housing in the open market; 36 percent could afford home ownership provided they were extended long-term financing at a reasonable rate of interest. The remaining 50 percent could not afford shelter even at reduced rates.

The problems are too basic to be resolved merely by upgrading shelter; rather, what is needed according to the authors is a system to eliminate urban poverty and lack of education. In addition, there is annual need for 100,000 units to cover new households, population increases and replacement of slum and squatter houses. The problems are aggravated by the high cost of land and building materials.

The authors offer four recommendations: 1) the long tradition of indigenous building should be exploited to develop concepts for architectural adaptations to a harsh environment; 2) not only economics and technology, but the cultural practices and benefits of the people should be parameters in the design of their shelters; 3) environmental design and landscaping approaches may offer major benefits by reducing wind loads on structures; and 4) a systematic analysis of building components, for resisting not only high winds but also floods and earthquakes, should be undertaken. The proceedings, which include this paper, appeared as NBS Building Science Series 56 (see reference 3, page B-1).

A related low-cost housing design project was carried out by a Carnegie-Mellon University team headed by Dr. Charles H. Goodspeed and Professor Volker H. Hartkopf. Results have been published as, *Feasibility Test of an Approach and Prototype for Ultra-Low Cost Housing.* In 1974 and 1975 the team—which included architects, engineers, planners and sociologists—developed a prototype, very low-cost (goal: $10 per person per shelter) housing unit for use in a variety of relief and rural development situations in Bangladesh. The prototype an "A" frame modular housing system, accomodates a wide variety of local, indigenous materials. The structure is cheap, labor intensive easily erected and reportedly resists wind and floods. The prototype structure has yet to be systematically tested in a high-wind situation, so its performance under such conditions is largely unknown.

Dr. Vijai Singh, a sociologist on the team underscores a theme found in Volume 5—that of importance of cultural acceptance. He believes that the structures could be made more acceptable by lowering their height and changing their appearance to conform to the traditional structures. In this regard, several different door styles were tried, but none proved popular and residents suggested a bigger entrance and a door that could be shut and locked.

Local people complained about the tightness of space inside the structures and felt they had been built without due concern for the needs of the families living in them. Most complaints centered on lack of storage and kitchen space. Residents in some areas felt the windows were too high, and should be lowered so some air could flow at the floor level. It was difficult to sleep inside in hot and humid weather.

Three related economic reports came to the NBS team's attention as this project progressed and they deserve mention here. All are by Professor Fred Moavenzadeh, Department of Civil Engineering, Massachusetts Institute of Technology.[3] These unpublished reports, prepared for various United Nations agencies, offer the interested reader a useful overview of the typical economic status of housing industries in developing countries. The author examines these industries from the viewpoints of their management and financing problems as well as construction technology and materials. He points out that technical solutions to housing should involve a high labor content since labor is plentiful but foreign exchange, needed to import manufactured materials or to build elaborate domestic production plants, is scarce. In this regard, the author favors several new materials, such as plastics, that require a reasonably simple production technology. He advocates that the sites-and-services concept be included in municipal or regional zoning programs in developing nations.

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[3]Moavenzadeh, Fred, *Building Operation and the Choice of Appropriate Technologies for Conditions Prevailing in Developing Countries* (December 1975); *Shelter: Experience, Problems and Solutions Related to 'Formal' Building Industry* (2nd Draft, December 1975); and *Industrialization of Production and Assembly of Prefabricated Elements and Components Prepared for Joint Consultation on Prefabrication for Industrial Construction* (UN Industrial Development Organization, Poland, Sept./Oct. 1975).

Facing Page: ***Millions worldwide live in houses highly vulnerable to winds. Activities such as these under technology transfer will make future homes, and lives, safer.***

3. INFORMATION TRANSFER

A basic concern of the NBS/AID high wind project has been the need to transfer the project findings to the various organizations and individuals in developing countries who face the possibility of human and property loss due to high winds. These target groups of users are:

- Government policy makers
- Private developers
- Regulatory officials
- Financial lending institutions
- Design professionals
- Manufacturers
- Professional architectural and engineering societies
- University staff
- Local craftsmen
- The general public—as building user and tenant

The proposed plan for transferring information to these groups recognizes their different backgrounds and information requirements. For example, local craftsmen and the general public in some cases may need rather unsophisticated written information but will readily comprehend various types of visual material. Thus, drawings with minimum text are essential. By contrast, design professionals require information at a higher technical level. Information transfer, was initiated through several approaches. They are discussed below.

3.1 REGIONAL WORKSHOP/CONFERENCES

As noted in section 2.2.2, one workshop and two conferences were held during the course of the project—two in Manila and one in Kingston. These meetings gave individuals from the building community the opportunity to present papers, to learn about research results to date, to ask questions, and to speak out as to the future direction fo the project. Another benefit was that of establishing solid working relationships with many of the prospective users of the research findings.

The results of these communication efforts are significant. In the Philippines, project information provided the first step in revising the National Building Code (Section 2.05, Wind Pressures) and this will lead to improved building practices. The Commonwealth Caribbean countries are in the process of upgrading their building code. This project's information will be considered as their building code is revised. Bangladesh, Haiti and other developing countries will use portions of the technical information in revisions of their building code.

Transfer is not limited to developing countries. Test data will be made available to the subcommittee on wind loads of the American National Standards Institute for possible incorporation into American National Standard A58.1—*Minimum Design Loads in Buildings and Other Structures.*

3.2 WIND REFERENCE COLLECTION

Two copies each of 75 documents dealing with wind effects on buildings and other engineering structures were transferred to the Philippines Advisory Committee. One copy was placed in the University of Philippines Library. These reports serve as a comprehensive library collection. The reports are listed in Appendix C of NBSIR 74-567 (see reference 2, page B-1).

3.3 16-mm SOUND MOVIE

An 18-minute user-oriented 16-mm color and sound movie, entitled "Extreme Wind Study," was produced by NBS (see reference 9, page B-1) which summarizes the high wind research project. It is aimed at several audiences, technical, semi-technical and the general public.

By illustrating the destructive effects of winds on buildings, the film tells viewers about the NBS field testing acitivities as well as the wind tunnel testing program. Computer graphics are used to depict the actual effect of wind on buildings. Filmed mostly in the Philippines, it shows the three test sites, the wind tunnel, and the participation of the NBS team as well as architects, engineers, building officials and university staff at the workshop and test sites.

Through December 1976, 28,000 individuals had viewed the film. These people represent professional societies, academia, trade groups, U.S. Federal Agencies and schools. The film was awarded a Silver Cup-First Place, at the 10th International Educational and Television Film Show at the Rome Fair held from May 29-June 13, 1976.

***Facing Page:** Technicians install pressure sensor on a test house at Daet, Philippines.*

4. ACCOMPLISHMENTS OF THE NBS/AID HIGH WIND PROJECT

The project has demonstrated that it is possible to design and build safer low-rise buildings at an acceptable cost by: a) using improved criteria in determining wind forces on low-rise buildings; b) reliable planning, design and construction practices; c) using a simplified method for forecasting housing needs; and d) providing sound principles which allow for local housing preferences and traditions.

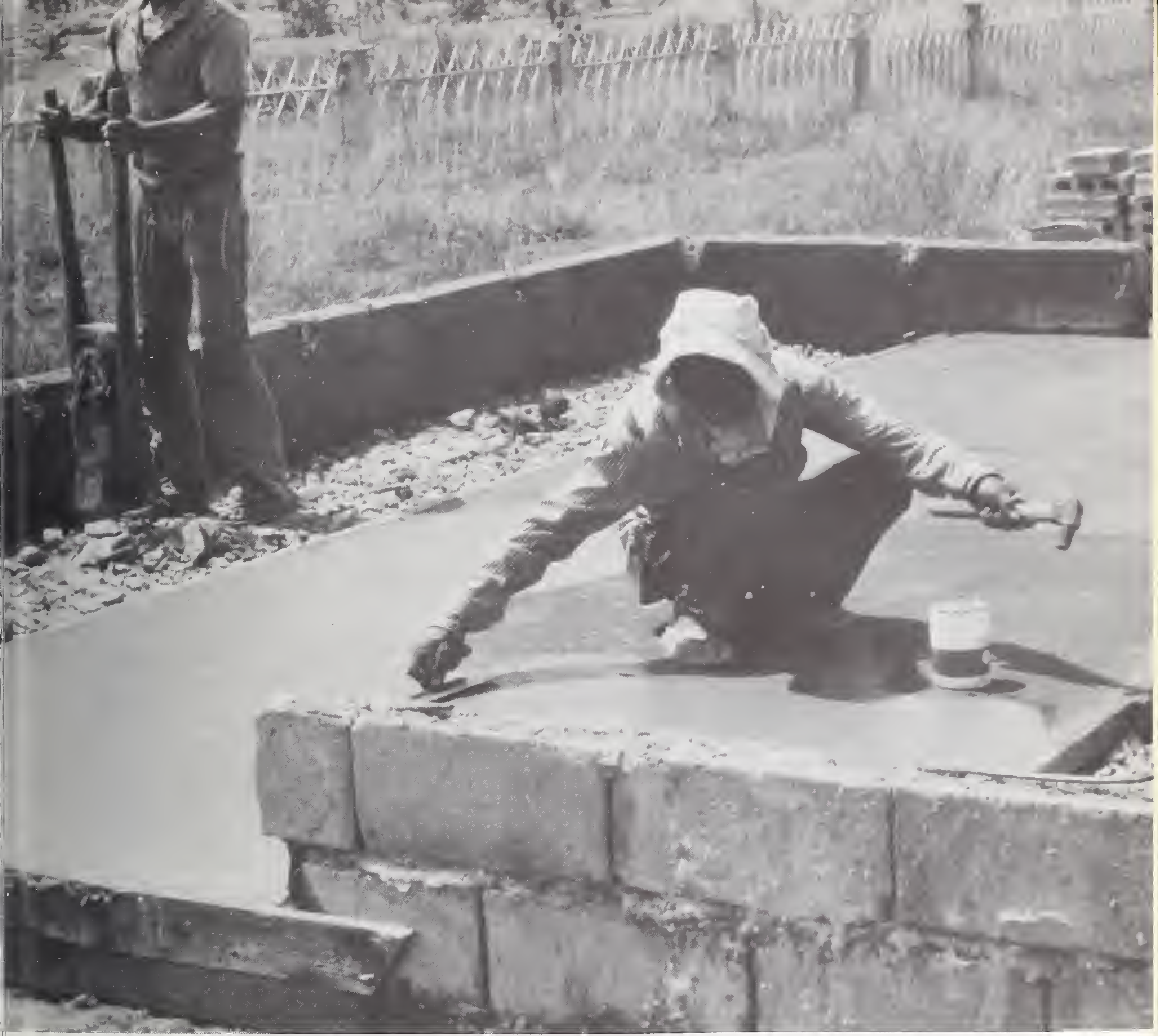
There have been six major benefits as a result of this project:

- Improved design criteria have been developed to guide architects, engineers and builders.
- By means of workshops and the various other information transfer vehicles, greater concern has emerged in developing countries for improved ways to guard against the effects of extreme winds, and for the methods to do the job.
- Interactions between members of the building

community representing government, industry, professional and academic groups and decision makers in the participating wind prone developing countries were stimulated by this project.

- Vital training of professionals and technicians has begun in developing countries for carrying out wind measurement and analysis procedures.
- Essential but scattered documentation on good practices has been identified for use by the building community.
- Technical information has been tailored to meet the user's needs.

Facing Page: *Workmen lay a foundation for one of the project's test houses. Such research will be the basis for improving building practices.*



5. NEEDS AND RECOMMENDATIONS

Important tasks remain to be completed if annual losses of life and property due to extreme winds are to be brought under control. To this end nineteen recommendations were developed:

1. Establish a national center in developing countries to promote information exchanges with meteorologists and climatologists, the design professions, regulatory officials, building authorities and local craftsmen on matters concerning the design of buildings to resist wind forces.
2. Establish comprehensive programs of improved land use planning to reduce the damage potential of extreme winds and heavy rainfall.
3. Encourage meteorological agencies and related groups to collect mean-hourly wind speed and peak gust data and disseminate this information in a useful form to private and governmental groups involved with building design and construction.
4. The meteorological services in developing

countries which regularly experience hurricanes or typhoons should take the lead in improving the distribution, density and siting of wind observation stations.

5. Buildings having unusual shapes and structural characteristics that are not covered by recognized codes of practice should be subjected to appropriate wind tunnel model studies.
6. Provide for conducting post-disaster surveys by appropriate government and private groups.
7. Establish an international wind research center and support it through appropriate organizations to study the effects of winds on buildings.
8. Incorporate project test results in the codes and standards of developing countries and have these done in a format easily understandable by local urban and rural officials.
9. Recommend that standards-generating committees in developing countries take note of the findings of this project as they consider development of new or revised standards for wind-resistant construction.
10. Architects and engineers in public and private practice entrusted with building design and construction supervision should be licensed by an appropriate professional licensing board.
11. The professional engineering and architectural societies should work closely with colleges and universities to develop courses of study for engineering and architectural students related to the effects of wind on buildings.
12. Develop and carry out programs of continuing education at all levels of society for individuals involved in the design and construction of buildings.
13. Structural design for wind loads should take into account the local wind climate and the effects of surrounding terrain and neighboring structures on the characteristics of surface winds.
14. The design of roofing and cladding elements should consider the effects of local pressure fluctuations near the corners of walls, along the edges of roofs and under eaves.
15. Conduct a pilot program to develop, design, build and evaluate housing in selected regions subject to high winds, using recommended good practice, and based on major involvement of local people in site selection, planning, design, manufacture of components and erection.
16. Explore further the problems of maintaining soundly built housing to preserve its resistance to high winds.
17. Evaluate the actual use in participating nations of the content and format as required to obtain the broadest possible dissemination in each of those nations.
18. Explore channels for expanding information linkages with all nations and regions subjected to extreme winds.
19. Investigate further the transfer of information to the local craftsman level.

Appendix A PARTICIPATING ORGANIZATIONS

The following organizations participated in and made valuable contributions to the research project.

Bangladesh
- Bangladesh University of Engineering and Technology
- CARE, Inc., Bangladesh

Haiti
- Ministry of Public Works

Jamaica
- Douet, Brown, Adams and Associates, Consulting Engineers
- Jamaican Bureau of Standards
- Jamaican Institution of Engineers
- Jamaican Meteorological Office
- Kingston and St. Andrew Corporation, City Engineers
- Ministry of Housing
- Social Action Center

Japan
- Kyoto University
- Ministry of Construction

The Philippines
- Association of Structural Engineers of the Philippines*
- Bureau of Public Works*
- Civil Aeronautics Administration*
- Forest Products Research and Industries Development Commission*
- Government Service Insurance System*
- Land and Housing Development Corporation*
- National Building Code Committee*
- National Housing Corporation*
- National Institute of Science and Technology
- National Science Development Board*
- National Society for Seismology and Earthquake Engineering of the Philippines*
- People's Homesite and Housing Corporation*
- Philippine Atmospheric Geophysical and Astronomical Services Administration*
- Philippine Institute Housing Corporation*
- Philippine Atmospheric Geophysical and Astronomical Services Administration*
- Philippine Institute of Civil Engineers*
- Philippine Standards Association*
- Social Security System*
- University of the Philippines*

Republic of China (Taiwan)
- National Bureau of Standards

United Kingdom
- Building Research Establishment Department of the Environment

United Nations
- United Nations Economic Commission for Asia and the Far East

United States of America
- Agency for International Development, United States Department of State (Project Sponsor)
- Agency for International Development Missions; Manila, Philippines; Kingston, Jamaica; Dacca, Bangladesh; Port-au-Prince, Haiti
- Care, Inc.
- Colorado State University
- Forest Products Laboratory, Department of Agriculture
- National Bureau of Standards*, Department of Commerce
- United States Air Force
- Virginia Polytechnic Institute and State Univeristy

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*Member, Philippine Advisory Committee.

Appendix B REFERENCES

This appendix is divided into four sections; a) project output references, b) wind measurements and design loads, c) socio-economic factors and housing characteristics and d) planning, design and construction technology. Each section lists reports and other documents under various reader interest headings. Under the first section are reports listed in chronological order as they were developed during the course of the project. The other three headings list reports used during the course of this project and documents which contain information relevant to the planning and design of low-rise buildings in wind prone areas.

Documents noted in the list of references by NTIS may be ordered from National Technical Information Service, US Department of Commerce, 5285 Port Royal Rd., Springfield, Va. 22161. Likewise, documents noted by Superintendent of Documents may be ordered from the US Government Printing Office, Washington, DC 20402. Other reports may be obtained by writing the author or borrowed from an appropriate library.

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