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## Complex Systems Engineering Principles— Active Response and Soft Failure:

A visit to the  
US Army Corps of Engineers  
in New Orleans

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**Preface:**

The U.S. Army Corps of Engineers (USACE) invited Professor Bar-Yam, president of the New England Complex Systems Institute, to give an executive program to senior management to provide training in complex systems science concepts and their application to areas of interest to the USACE. In preparation for this program, Professor Bar-Yam was provided a tour of the USACE engineering and construction efforts in New Orleans. These efforts were developed following Hurricane Katrina under the supervision of Task Force Hope of the Mississippi Valley Division of the Civil Works programs of the USACE. Tours of the new pump station at the 17th St. Canal and the surge protection barrier by boat were included, as well as a visit to the Gentilly neighborhood. Gentilly was largely destroyed by flooding during Katrina, similarly to the Ninth Ward, which has received more media attention. The tour provided key information about the opportunities and challenges facing the civil works program of the USACE, including the natural, social and technological components of the systems being confronted, and the organizational structures within USACE that are used to accomplish their tasks. Project Hope is currently at the peak of construction in view of a completion deadline of June 2011. Along with other examples within USACE, the relevant “lessons learned” from the project will inform the executive program.

Following the tour, NECSI met with Col. Gunter and risk reduction specialist Reuben Mabry to discuss some insights from complex systems science that may inform future efforts to achieve risk reduction beyond the current program plans. This report describes some of the principles at work in Project Hope and the complex systems insights discussed with Col. Gunter and Mr. Mabry.

## Introduction

Project Hope of the U. S. Army Corps of Engineers in New Orleans is a large scale \$14.45 billion engineering and construction effort. It is strengthening the New Orleans levee system through larger and better designed floodwalls and levees, and new pump stations—designed and executed within the constraints of coupling to navigation, and environmental concerns.

A central tenet of the USACE project is that it is not building a "protection" system but rather a "risk reduction" system. It is impossible to protect from all possible levels of storm surge. Instead the current goal of the system design, for completion in June 2011, is protection against a storm with a probability of 1% in any given year.

The New Orleans engineering project, including its rapid execution timeline, provides an important case study for comparison with complex systems concepts.[1,2] Insights from complex systems science enable us to understand how to effectively generalize these concepts to other areas of activities. For example, organizational structures can be utilized in multiple contexts, as long as the conditions under which they are applicable are recognized.

Among the complex systems principles at work in the program are:

- Separating complex (high variety) tasks from highly-repetitive tasks, and using appropriate methods for each: [1-3] Use of competitive "evolutionary" process for the most complex engineering aspects of the program, specifically the design, while using mass production techniques for highly-repetitive large scale construction.
- Creation of new reduced length perimeter boundary (skin) around protected zone, i.e. collective protection rather than ward by ward protection.[4] This is manifest in the gates at the outfalls of the drainage canals and in the Lake Borgne barrier, which also distances the line of protection from the central areas.
- Distributing responsibility [2,5] through designation of areas of New Orleans to different Mississippi districts of USACE. These divisions engaged in design projects for their designated area of New Orleans.
- Modularity of design and organization [6,7] of many aspects of the program, including the modularity of the design for different areas of New Orleans, and modularity of the design-build process that allowed initial designs to be implemented while others were still in design stages.

Here we discuss two additional principles that have more limited realization in Project Hope and could be more widely adopted. They augment the core strategy of risk reduction by focusing on the extent of failure at the point at which the system no longer provides full protection. We recommend them for flood damage reduction challenges across the nation, both future ones and in evaluation of existing projects.

- Active response through dynamically implemented methods of protection.[8] This is present in the closure during a storm of flood gates and the Lake Borgne barrier navigation gates. It is also present in the possibility of diverting flood waters into the Bonnet Carré spillway.
- "Soft failure" design so that the system does not fail catastrophically but only incrementally at the point of failure. A small amount of flooding can occur without serious damage, as it occurs in many other places. "Soft failure" design is present in the armoring of the back sides of levees, and the use of T-wall construction, which inhibit catastrophic failure when over-topping occurs.

These are described in the following sections in greater detail.

## **Active response**

The primary approach to protection from hurricanes and other natural disasters is the construction of robust structures that withstand the forces exerted upon them. We consider this kind of robustness to be a passive design strategy. A complementary strategy is an active response strategy.[8] The ability to respond actively requires sufficient information in advance of a potential crisis to enable decisions about actions to be taken, and the facilities to make those decisions. An important strength of this approach is that it is adaptive. Through experience it can be modified to consider new information as it becomes available. While passive systems can also be modified over time through new construction, the active system can be designed for ongoing adaptive learning. Active response with decision-making during flood events requires, and self-consistently promotes, awareness and preparedness at a higher level than purely passive measures. It can be used in addition to passive systems, rather than as a replacement of them.

Historical active response strategies include warnings using hurricane prediction, and the evacuation of coastal areas, including the possibility of New Orleans evacuations.

The USACE is currently engaged in constructing active response facilities that include two projects:

First, the construction of closable walls at the outlets of the canals on Lake Ponchartrain to prevent storm surge from entering the canals, a key part of the failure of the system during Katrina. The walls are to be closed prior to a storm surge, and new pumps are designed to evacuate the water from the canals to the lake. The system could

be a passive one that operated all the time, but there is no need for it to do so. Thus, an active system is in place with real time decisions about when to use it.

Second, the construction of a closable navigation gate as part of the new surge barrier. The navigation gate is designed to be closed just prior to a hurricane, because the use of the gate for navigation prevents its closure at other times.

In addition, when high levels of the river create a flood risk, the Bonnet Carré spillway on the Mississippi above the city can divert flood waters. Such diversion can impact the environment and recreational activities. However, it is designed to reduce risks of large scale disruption of the city from high levels of river water.

A new way that this approach might be used in the case of a hurricane would be to lower river levels to prevent surge overtopping. Before Katrina, the level of the river was lower than normal. The city's river levees did not breach. In a future storm, if the river levels are high in advance of the storm, it may be possible within a 48 hour warning window to lower the river level to reduce the level of risk from surge. Other aspects of the impact, such as on the level of water in lake Pontchartrain, would have to be considered. The benefit can be evaluated through experimentation during storms that are not catastrophic in size, and through dynamic modeling. In order for this to be possible, the spillway system would need to be modified. Currently, the system has a 12 foot sill that prevents reducing the level of the river below 12 foot above baseline river levels. The sill and related structures would have to be changed to allow for active river level control that would reduce the risk of high hurricane storm surges overtopping the river levees.

A well-established and still widely used active response is the construction of temporary flood barriers using sandbags. A modern version that may have some benefits in certain conditions is the use of water-filled inflatable bags. This approach adopts a strategy of fighting water with water: making use of the material that is most available during a flood.[9] Inflatable bags have been developed by a number of companies[10, 11] and were used in limited degree in the response to Hurricane Rita in New Orleans.[12] With sufficient planning, inflatable bags might be used to augment levees and flood walls using anchors that are installed in advance.

## **Soft failure**

If a system is designed to protect the city against a storm surge of 12 feet at some point, and the surge reaches 13 feet, what is the consequence? Does one foot or 13 feet of water reach the city? This may be the difference between non-harmful low levels of flooding in the former case, and the kind of destruction found in Katrina in the latter case.

A "soft failure" system does not fail catastrophically when conditions exceed specified protection levels (see Figure 1). This means that when there is a storm surge

that is higher than levels at which the system is designed to operate, the system fails gracefully, resulting in limited flooding but not catastrophic failures. Allowing a low flooding level at the point of failure, such as one foot of water, rather than levee breaches causing floodwaters that carry away houses, is the objective.

Non-catastrophic flooding occurs commonly in many places.[13] However, creating a system that includes plans for such flooding is not generally considered in flood control efforts such as in New Orleans. Given the recognition that flood protection is a risk reduction, it makes sense to design the system to reduce not just the risk of a catastrophic flood but also the damage. Thus, for example, while reducing the level of any flooding to less than 1% per year, one might reduce the level of catastrophic failure to one in a thousand. The concept also allows for non-catastrophic flooding that reduces the risk of catastrophic flooding, by reducing the pressure on the critical parts of the system, or more generally, through allowance of some of the excess water to reach the city rather than all the water to reach the city when a large storm occurs.

Discussions with USACE indicate that many features of soft failure are already incorporated in the current design; however, the design is not fully conceived and planned with soft failure in mind, and therefore there is reason to consider whether it should be a design strategy. Features that already include the soft failure strategy include some walls and levees that are designed to be overtopped, without breaching; water can flow over them without the structure itself losing its integrity and failing through collapse or erosion. For example, some of the walls are designed so the back side can withstand the presence of water. This results in only part of the water reaching the city—the excess, but not the bulk of the storm surge.

In addition to the existing strategy, there is discussion of adopting approaches that are in various stages of implementation in the Netherlands, including flood bypass “green rivers” and retention areas, allowing limited flooding and water accumulation in specific areas that are designed for the purpose.[14-18] Avoiding land use that would conflict with limited local flooding is natural if such low levels of flooding are sufficiently common.

Thus, examples of soft failure design include: whether water flow over the structure will degrade the structure, whether the backside of the structure is protected against the presence of water, and whether limited floodwater in the city has places to flow by design.

The soft failure concept is related to but not the same as the concept of “fail-safe” or “fault tolerant” systems,[19-21] though we may consider soft failure as included in a generalized fail-safe concept. Fail-safe systems are generally designed so that component failures have limited impacts on the system as a whole. In soft failure systems the components of a protective system continue to function even when tolerance levels are exceeded, resulting in significant levels of protection.

Active response and soft failure are both present in a historical example of flood response in New Orleans in the face of flooding in 1927.[22] A levee was breached using explosives by direct action of the authorities, flooding agricultural areas, to reduce the risk of flooding of New Orleans itself. This reflected a choice of lower level of failure (soft failure) to avoid higher level of failure and represented an action taken at the time of the potential crisis, (active response). Rather than making such choices without their being a planned part of the system design, it is possible to design the system for active response.

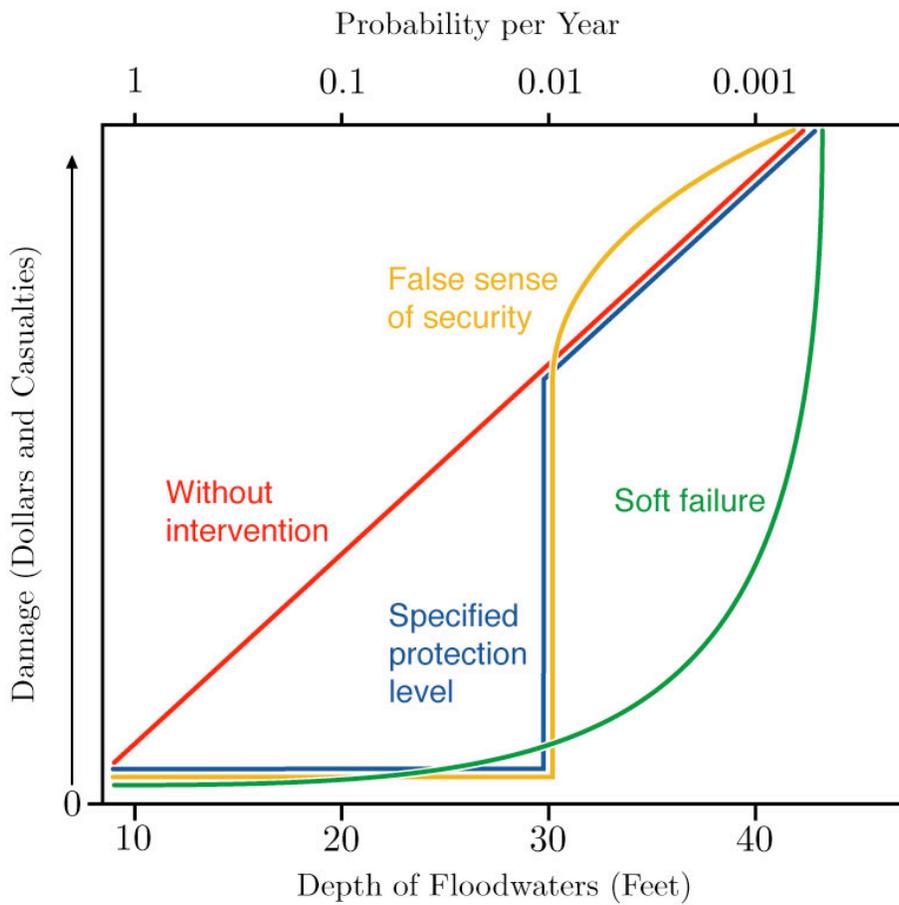


Figure 1: Schematic diagram of different strategies for flood damage control.

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