3. ENGINEERING of DUNES

Protection Benefits of Coastal Sand Dunes

In addition to providing critical habitat for a variety of coastal species, coastal sand dunes are an integral part of a well-planned coastal defense system. Coastal sand dunes act as reservoirs of sand that help the beach maintain its natural equilibrium and preserve the ability of the beach to respond naturally to storm events. Beaches naturally evolve during a storm by taking on a more dissipative state that helps break waves further offshore, reducing the wave energy near the shoreline. To the casual observer, this transition to a more dissipative state manifests itself as a reduction in beach slope and the formation of one or more offshore bars. These bars are formed by the offshore transport of sand from the beach face during the peak of the storm. The bars mark the location of the most intense wave breaking during the storm. During less intense storms, the waves don't reach the base of the dune, and the erosion is limited to the beach face (berm) itself. The dunes become active during moderate to large storms when the dissipation created by the bars is insufficient to prevent the waves from attacking the base of the dune. This results in erosion of the dune which releases a portion of the built up reservoir of sand into the system. This sand is then redistributed across the profile to help create the dissipative profile which minimizes further erosion and damage to inland infrastructure. The larger the dune, the more time it takes for it to be eroded by the waves, and therefore the more protection it provides to areas behind the dune. In the simplest terms, the sand stored in the dunes buys time and protection from severe storms. It takes time for the waves to move sand offshore; therefore, the bigger the reservoir of sand, the more time it takes for the waves to consume the dune.

Dune Design Guidelines

Although dunes of nearly any size are beneficial, in order to be considered as a barrier to coastal flooding, coastal sand dunes need to meet the size criteria established by the Federal Emergency Management Agency (FEMA). Based on an analysis of dune erosion during hurricanes, FEMA has identified the amount of sand stored within the cross-sectional area of the frontal half of the primary dune, above the 100-year still water elevation (Figure 1) as the critical parameter for protection against a 100-year storm event. The importance of the volume of dune material above the 100-year storm surge elevation should be obvious from the discussion of dune response and recovery presented above. A dune that is predominantly below the 100-year storm surge elevation will be overwashed and will not provide much protection. During the overwash process, the dune sediments are transported both seaward into the littoral drift and landward into the back dune. This results in a significant landward migration of the dune, and along developed shorelines, could ultimately cause the loss of the dune. A dune that is only slightly above the 100-year storm surge elevation will typically undergo significant scarping and erosion and the dune will significantly deflate, reducing in height and width. Studies by Hallermeier and Rhodes (1986) and Dewberry & Davis (1989), found that 540 ft^2 of sand per linear foot of dune was required to provide adequate protection during the 100-year storm. As a result, FEMA's current V-zone mapping procedures (FEMA 1995) require that quantity of material in the cross-sectional area of the frontal half of the primary dune, above the 100-year still water elevation, in order for a dune to be considered as substantial enough to withstand erosion during a base flood event. This criteria is commonly referred to as the FEMA 540 rule.

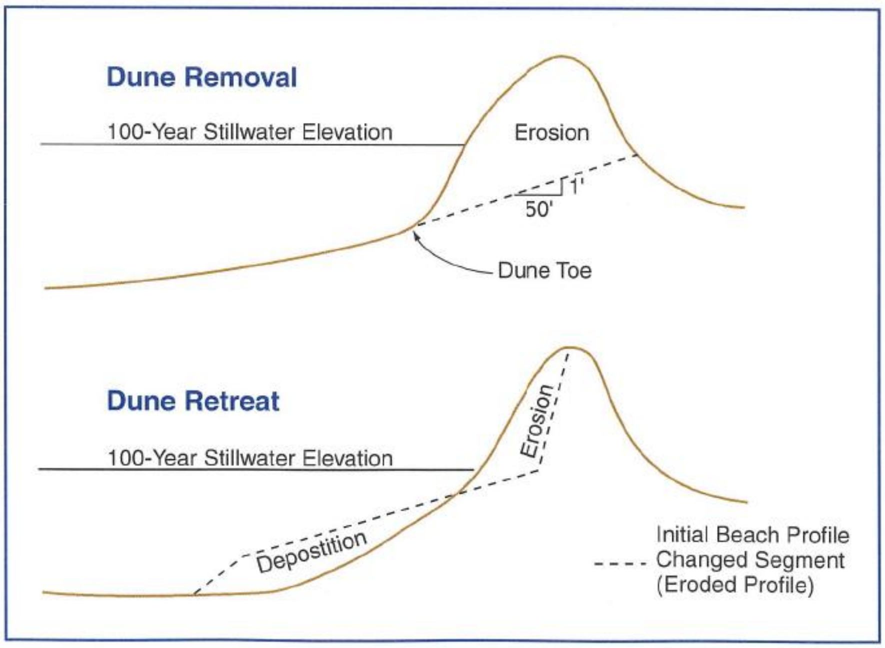

Figure 1. FEMA's current determination of dune retreat and removal.

More recently, post-storm surveys have indicated that an even larger volume of sediment is necessary to withstand significant erosion events. The revised FEMA Coastal Construction Manual (FEMA, 2000) recommends a minimum frontal dune volume of 1,100 ft^2 per linear foot of dune in the front half of the dune above the 100-year still water level. Since the National Flood Insurance Program (NFIP) regularly encourages communities to establish standards above the minimum NFIP standards, New Jersey has taken the proactive step of requiring dunes to fulfill the higher frontal dune volume in the NJ Coastal Zone Management Regulations. Most dunes in New Jersey do not meet this criteria; however, frontal dune volumes as great as 800 ft^2 per linear foot of dune have been established in several communities with the help of dune fencing and planting. These dunes are typically 250 feet wide and 16 feet high at the crest (Mauriello, 1990).

Human Induced Modifications of Dune Systems

The ability of a dune to withstand the extreme forces during a severe storm event can either be enhanced or diminished by human modifications to the dune system. Dunes are dynamic features that are intended to erode during extreme storm events, and then recover naturally when storm conditions subside. Although robust dunes have been shown to be extremely effective in minimizing damage during even very large storm events (STEW FARREL Shore and Beach), sometimes, the threat of a dune breaching is something that a community is unwilling to bear. In the wake of Superstorm Sandy, several New Jersey communities decided to add non-erodible structural cores to their dune systems as a way of minimizing damage during future storm events. Structural cores generally consist of a geocore (sand encased in a geotextile fabric, see section below for details), rock, or steel sheetpile wall embedded within an existing or proposed dune system. The intent is to combine the aesthetic and environmental appeal of a dynamic beach and dune system with the robust storm protection provided by the structural core. While stabilizing the core of a dune can have significant benefits, there are several important factors which must be considered. Generally, any hard structure will accelerate erosion of the beach immediately fronting it, if left exposed to wave impact on a regular basis. Therefore, any dunes with a structural core must be properly maintained to ensure that no sections of the core are left exposed after a severe storm. **For this reason, it is critical that these structures are considered within the context of a larger beach management strategy which addresses the long term sustainability of the beach and dune system.**

As with all coastal structures, scour in front of a dune core and erosion at the ends (flanking) is also a significant concern when exposed to regular wave activity. A known, but somewhat less common phenomenon that was identified as a common cause of significant damage to both coastal structures and the infrastructure behind them during Sandy, was scour generated by waves overtopping the structures. At multiple locations the scour effect was exacerbated by the receding surge, which in some cases toppled structures from the landside (Miller, Rella, & Hopson, 2015). Therefore, if dune cores are incorporated into the design of a comprehensive beach/dune system, it is important that scour, overtopping, and flanking are addressed in the project's design through the provision of toe protection, splash pads, and edge stability measures.

Geocore

Geocore refers to one of several approaches in which the natural beach sand is encased in a container made from a material called geotextile. Geotextile is a synthetic woven product that is used in many soil stabilization projects to increase the strength of the soil and promote drainage. The two most popular forms of geocores used in beach stabilization projects are geotubes (Figure 2) and geocubes (Figure 3). The geotextile containers are manufactured offsite and are shipped to the installation location empty. Once onsite, the containers are filled mechanically with sand from the beach on which they are being deployed. Geocores are frequently viewed as a quasi-soft approach to shoreline stabilization and in some locations, may be preferred over rock and/or sheetpile. Once plagued by durability issues related to vandalism and sunlight degradation, modern geotextiles have largely overcome these issues.

Geotubes come in a variety of shapes and sizes. The most common type for dune stabilization applications is oval in shape, with a diameter of between 4 and 8 feet. The geotube casing is generally pre-fabricated offsite, then shipped to the project site where it is filled by pumping a water-sand mixture known as a slurry, into the casing through a fill port. The geotextile material is porous, so the water percolates through the fabric, leaving behind a large diameter, sand-filled tube. Geotubes have been used in several locations throughout New Jersey, including Strathmere, Atlantic City, and Ocean City on the ocean coast, and at Mordecai Island, which is located in a bayshore environment. In Ocean City, the geotubes were installed in the dune system as part of a dune restoration project that was completed just prior to Superstorm Sandy. Although the most severe impacts during Sandy were experienced well north of Ocean City, during the storm, the geotube core successfully absorbed the wave impacts, reducing damage to the community.

Geocubes are a relatively new and less commonly used approach for stabilizing coastal dunes. Like geotubes, geocubes come in a variety of sizes and can be customized to the specific application. Geocubes are typically filled mechanically using an excavator. Unlike geotubes, in which the sand fills a single large compartment, geocubes are generally smaller individual units or a system of interconnected units as shown in Figure 3. One of the advantages of working with smaller units, is that if a single unit or compartment fails, the integrity of the structure as a whole is generally preserved. Currently, the only known geocube installation in New Jersey is an experimental system deployed in Ocean City after Superstorm Sandy.

Figure 2. Exposed geotube after Superstorm Sandy in Ocean City, New Jersey.

Figure 3. Trapbag geotextile (geocube) container installation in Ocean City.

Rock

Generally, rock dune cores are constructed as rock revetments backing an already existing beach. The structures are usually covered in sand, and in some cases, planted with dune grass to improve the overall aesthetic appeal of the project. Rock cores should be designed as fully functioning revetments in the event they become exposed during a storm. Design guidance for revetments can be found in both the Coastal Engineering Manual (US Army Corps of Engineers, 2002) and the Rock Manual (CIRIA; CUR; CETMF, 2012). After Superstorm Sandy, the Borough of Bay Head, in New Jersey, became an example for other communities interested in employing a rock dune core design, by proving how beneficial a rock core can be during a severe storm event. The majority of Bay Head's oceanfront property was protected by a historic seawall (Figure 32), and as a result, the town only experienced minimal damage during the storm. Whereas, the community immediately to the south, the Borough of Mantoloking suffered extensive damage during the storm (Walling et. al., 2014) (Katie and VaTech work). It should be noted that while the relict seawall definitely played a significant role in reducing storm damage in Bay Head, there were a number of other differences between the two communities that also contributed to the difference in observed damage.

Figure 4. Exposed dune rock core after Superstorm Sandy in Bay Head, New Jersey.

Sheet Pile/Bulkhead

Most modern sheet pile dune core projects are constructed using steel or vinyl sheet pile; however, many of the older bulkhead projects were constructed out of timber. Steel/vinyl sheet pile is typically used due to its durability and ease of construction. Similar to other dune core stabilization approaches, the intent of the sheet pile wall or bulkhead is to function as a last line of defense during severe storms. Steel sheet pile walls and/or bulkheads have been widely used throughout New Jersey. Many of the older walls are timber bulkheads which were intended to serve as the coastal protection for the communities located behind them. Several communities have decided to utilize sheet pile bulkheads to form a dune core to prevent breaching of the beach and dune system during a severe storm. This technique has been incorporated at several shoreline locations in New Jersey, including Sandy Hook and Mantoloking. The project in Mantoloking was undertaken as a direct result of the catastrophic damages experienced during Sandy, where the barrier spit breached in multiple locations.

Figure 5. Sheet pile dune core (picture taken shortly after installation, before it is capped and buried by the dune), in Brick Township, New Jersey (Sheetpile installation).

Walkways/Crossovers

The protective value of a coastal dune is maximized when the dunes are continuous. Any break or gap in a dune becomes an area where the erosive power of storm surge and waves are concentrated. Typically, water seeks the path of least resistance and is funneled toward any gap or low spot in a dune. Unfortunately, since natural dunes are made of erodible material, the concentration of the flow accelerates erosion along the flow path. In order to avoid creating this hazardous condition, dune walkovers are considered the preferred means of beach access, since they allow the dune line to remain continuous.

Dune walkovers are typically timber structures consisting of stairs and/or ramps on both the front and backside of the dunes, with a flat deck-type structure across the dune crest. Ideally, the walkover structure is constructed in such a manner that it does not interfere with natural dune processes, including the movement of sand and the growth of dune vegetation. Dune walkovers are often used in areas where there is heavy foot traffic, and typical dimensions are dependent on the intended use of the structure. A full guidance for constructing walkover structures in New Jersey can be found in the New Jersey Coastal Zone Management Rules, section N.J.A.C.7:7E. In general, for multiple family or public beach accesses, the walkover structure must not exceed 6 feet wide in overall dimensions, and must meet a minimum of 3' - 10" clearance above the dune crest. Walkovers for single family use are limited to 4 feet wide and require a minimum of 3' - 0" of clearance above the dune crest. Structures are intended to pose the least possible amount of disruption to the natural dune, and thus are required to terminate at either 10 feet seaward of the line of permanent beach dune vegetation, or at the toe of the frontal dune. Support posts are not to be encased in concrete, should have a minimum soil penetration of 5 feet, and should allow for the erosion of sand during a storm event. (Beach and Dune Walkover Guidelines)

Although, preferable from a coastal protection standpoint, there are some locations and situations where dune walkovers are not possible or necessary, such as areas of minimal dune development, sparse vegetation, or low foot traffic. In these cases, there are several alternatives which may be used to provide access at grade. The least preferred method is a shore-perpendicular street-end cut. Shore-perpendicular entrances provide minimal resistance to waves and surge, and they provide a conduit for funneling high-velocity flow directly inland. If beach access must be provided at grade, two preferable alternatives, which provide at least some additional storm protection, include angling the entrances to at least 45 degrees with respect to the shoreline, or to incorporate a small blockading feature at the end of the path on the seaward side, in attempt to deflect the surge from flowing straight through the access way. In both cases, the intent is to deflect or divert the flow of potential storm surge. On grade footpaths are limited to 6 feet in width, and the use of solid concrete or stone paths are generally not permitted due to their potential of becoming dangerous projectiles in a storm event. The use of geotextile fabrics or cabled wood planks should be reviewed on a case-by-case situation. On grade footpaths are not to be used where an escarpment between the dune structure and beach berm is present. (Beach and Dune Walkover Guidelines)

Figure 6. (a) Wooden dune walkover (preferred method) (Dune walkover); (b) angled walkway through dune; (c) shore-perpendicular walkway through dune (least preferred method).

Beach Nourishment and Dunes

In New Jersey beach nourishment projects have been designed and constructed both with and without dunes. Projects that include a dune generally specify a trapezoidal cross-section with regularly spaced plantings (typically American beach grass). Recently, there has been some suggestion that the specifications should be modified to allow for the construction and planting of more natural dune forms; although, there has been no formal adoption of these suggestions. Generally, the projects designed without a dune have higher and wider berms to compensate. These flat berms which can be 150 to 300 feet wide contain an ample supply of sediment for natural dune development (Figure 7). The rate at which the dunes will grow depends on the rate at which sand is transported onto the dune from the beach berm and on the effectiveness of the vegetation, fencing, and/or the dune itself in retaining sand. Both primary and secondary dune features (multiple dune lines) have been found on nourished beaches because of the enhanced sediment supply (Nordstrom and Mauriello, 2001). As an example, an 8.6 million yd^3 beach fill project to create a 100 foot wide berm in Ocean City, New Jersey, successfully re-established the natural cycle of dune growth (Nordstrom and Mauriello, 2001). Within 5 years of sand placement, both a primary and secondary dune developed in regions were only small foredunes previously existed.

Figure 7. A photo set showing the development of a dunes system after a nourishment project at a severely eroded beach.

Conclusion

Coastal sand dunes make up a very important feature of our beaches. Not only do they provide a natural habitat for local vegetation and animal species, but they also have the ability to provide significant protection from severe coastal storms. Artificially enhanced dune systems have the potential of providing even greater protection than naturally forming dunes, if properly designed and maintained. However, both natural and man-made dunes are part of a dynamic system, and will constantly change shape based on the environmental factors present at the site. In order to properly design and maintain a healthy beach and dune system, it is important for coastal communities interested in doing so, to first thoroughly understand the geomorphic processes of coastal dunes. The information presented in this report is intended to help communities become more aware of the functions of coastal dunes, and gain an insight of possible artificial dune design alternatives.