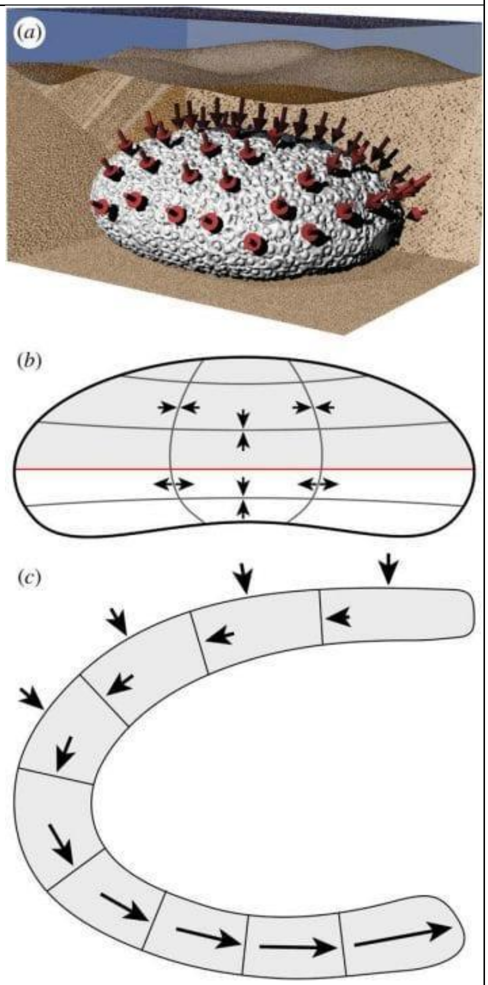
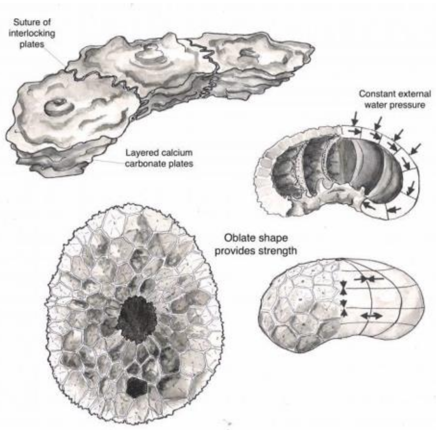
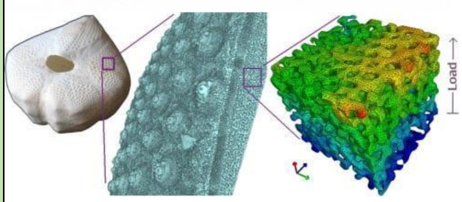
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	海膽外殼有效防止裂開及破裂 (Sea Urchin Shell Effectively Prevents Cracking and Breaking)
生物系統 LIVING SYSTEM	海膽 Echinoidea (Sea Urchin)
功能類別 FUNCTIONS	#應付擠壓#預防破裂/斷裂 #Manage Compression #Prevent Fracture/Rupture
作用機制標題	海膽外殼透過互鎖的骨板及扁球形狀防止破裂 (The shell of a sea urchin prevents breakage via interlocking plates and oblate shape.)
生物系統/作用機制示意圖	   
作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)	

海膽 (sea urchin) 的一生都在深約 1600 英尺的海底中渡過。在此深度的水壓十分巨大，每平方英吋約有 700 磅的壓力從四面八方擠壓著海膽。這就等同於被 20 隻大象壓著！令人

驚訝的是，海膽竟然可以承受如此巨大的壓力，並能健康生長而外殼不會產生一絲裂縫。雖然海膽外殼看起來易碎 (fragile)，但其形狀及結構能讓它十分強韌。外殼是由許多堅硬的碳酸鈣 (calcium carbonate) 小骨板 (small plate) 組成。碳酸鈣是由氧化鈣 (calcium oxide)、水，以及二氧化碳結合而成。碳酸鈣在大自然中很多地方都能找到，像是珊瑚、貝殼、石灰岩 (limestone rock) 等。碳酸鈣也是賦予水泥強度的物質。除了由堅硬的材料組成之外，海膽外殼上的每個小骨板也互相扣鎖 (interlock) 在一起，形成更強韌、更抗裂的外殼結構。

當掠食者嘗試啃咬海膽，其衝擊力 (impact) 會傳到每一片小骨板，而不是集中在單一片小骨板，這使啃咬的衝擊力分散到整個殼體，而不是單一的點。想像有兩類型的中空玻璃球，一顆是由單一片玻璃做成；另一顆是由許多小片玻璃拼接而成。如果單一片的玻璃球被刺穿，它可能出現裂痕並很可能粉碎；如果多片拼接的玻璃球被刺穿，其中一塊玻璃可能會裂開，但因為其結構，它還是能保持在一塊。海膽外殼比較不容易碎裂，是因為外殼上的衝擊力被分散到外殼不同塊的小骨板上。

除了小骨板的材料及排列方式外，海膽外殼也因其形狀而變得強韌。海膽外殼為扁球形 (oblate)，意味著就像扁平的球體。外殼因為持續的強大水壓而自然地生長成此形狀。此形狀可以藉由將力量分散到較大面積，從而減輕水壓集中在單一位點所帶來的影響，和互相扣鎖的小骨板作用類似。

海膽由於其外殼形狀及互想扣鎖的小骨板，使其能夠在嚴苛的水底環境不受傷害。其外殼能比想像中還強韌，因為能將造成傷害的力量分散到整個殼體。我們可以學習海膽的結構，用以建造更堅固、更輕量化、更能抵強大力量的建築物，如摩天大樓或風力發電機 (wind turbine) 等。

A sea urchin spends its life at approximately 1,600 feet underwater, at the bottom of the sea. At this depth, there is an enormous amount of pressure, approximately 700 pounds per square inch, from the water pushing down on the sea urchin in all directions. This is the same as being crushed by a stack of 20 elephants! Surprisingly, sea urchins can withstand this pressure and can grow without developing any cracks in its shell. Although the sea urchin shell looks fragile, the shape and construction make it quite strong. The shell is constructed of many small plates made of a strong material called calcium carbonate. Calcium carbonate is formed when calcium oxide, water, and carbon dioxide are combined. Calcium carbonate is found in many places in nature, including coral, seashells, and limestone rocks. It is also the material that helps give concrete its strength. In addition to being made of a strong material, the small plates on the sea urchin shell also interlock together, creating an even stronger and more crack-resistant shell structure.

When a predator tries to bite the urchin, the impact of the bite is transferred through all of the small plates rather than just one plate – this distributes the impact of the bite across the shell rather than to a single point. To picture this, imagine two types of hollow glass balls. One ball is made from a single piece and another is made up of many small pieces that fit together. If the ball made from a single piece is punctured, it will crack and the ball will likely shatter. If the ball made up of many small pieces is punctured, a single piece may be cracked, but because of its structure, it will stay together. The shell is less likely to break because the impact is distributed throughout the different pieces of the shell.

In addition to the material and the arrangement of the plates, the sea urchin shell is also strong because of its shape. The shell is oblate, meaning it resembles a flattened sphere. The shell naturally develops into this shape as it grows because of the constant intense pressure of the surrounding water. This shape helps relieve the impact of the water pressure on a single point by distributing the force over a larger area, similar to the interlocking plates.

The sea urchin is able to protect itself in the harsh underwater environment due to the shape of its shell and its interlocking plates. The shell is stronger than expected due to its ability to spread out damaging forces throughout its shell. We can learn from the sea urchin's structure to create stronger, lightweight buildings that are better able to withstand strong forces, like skyscrapers and wind turbines.

文獻引用 (REFERENCES)

「它與完美的泡綿的相似之處，為人造材料的最佳化設計提供了一個明確的仿生學(biomimetics)概念。這帶來了一個顯著減輕工程材料重量的可能性，例如交通工具中能減震而不用犧牲機械強度的材料…透過學習心海膽（heart urchin，猬團目 Spatangoida）如何製造輕量而具高度耐用性的外殼，能提供我們一個模板來改善人造材料，例如減震材料，或是為了保護資源。」

"Its likeness to an ideal foam, provide a clear concept for optimising design for manmade materials, biomimetics. This opens up an opportunity to significantly reduce the weight of engineering materials, e.g. shock absorbing materials in vehicles, without compromising mechanical strength… learning how the heart urchin produces its light-weight and highly durable shell can provide us with a template to improve man-made materials, e.g. shock absorbing materials, in order to preserve resources."

「緊密接合並互相扣鎖的小骨板，使外殼被認為呈現了一個單體式結構 (monolithic structure)。小骨板的建構以分明的區塊為特色，可被解釋為顯著的負載轉移系統 (load-transferring system)…在脊椎動物以及無脊椎動物的骨架中，圓頂形狀 (dome shaped) 的物體，以及骨骼基本部分 (skeletal element) 的縫合與互相扣鎖機制，關於它們的機械設計及功能已經被分析出來…向下施加的負載首先被轉換成橫向推力 (lateral thrust)。然後這種推力會平均地分佈到大致呈圓頂形狀的外殼上，這減輕了在特定區域上累積的壓力。具有長廊 (galleried) 的井骨 (stereom) 能將壓力傳遞到鄰近的小骨板，在該處被再次地、進一步地分散到周圍的小骨板。」

"The tight-fitting and interlocking plate joints lead to a shell considered to behave as a monolithic structure. The plate's architecture features distinct regions interpreted as a significant load-transferring system… Dome shaped objects, as well as the suturing and interlocking mechanisms between skeletal elements in both vertebrate and invertebrate skeletons have been analysed with respect to their mechanical design and function… Applied downward loads are firstly transferred into lateral thrust. This thrust is then distributed equally along the roughly dome-shaped shell, which reduces stress accumulation in a specific area. The galleried stereom can transfer stress to a neighbouring plate where it, again, is further distributed onto surrounding plates."

參考文獻清單與連結 (REFERENCE LIST)

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