航海氣象講座之十 船隻在風浪中的穩定性分析
https://youtu.be/JKUhvV9OqVk?si=CHoh1T7KUgD2VkPt
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參數橫搖的產生
參數橫搖是指船隻在船頭頂浪航行時產生的同步橫搖運動。當船頭被前面的浪抬起來時,如果船尾也被另一個浪抬起,就會產生船頭向一側(右)、船尾向另一側(左)的趨勢,從而導致船隻被加速向右甩動,產生參數橫搖。這種情況主要發生在貨櫃船上,而木材船等其他船型較少出現。

靜水中的穩定性
在靜水中,船隻的穩定性由重心和浮心的位置關係決定。當船體正浮在水面上時,重心如果在浮心之上,產生一個穩定的力矩,使船體保持平正。但如果船上貨物分佈不均勻,重心偏離中心,就會造成船體傾斜。

波浪中的穩定性
在波浪中,船隻的穩定性會發生變化。當船體傾斜時,浮心會向傾斜方向移動,與原來的重心產生一個回復力矩,使船體恢復平衡。但如果波浪過大,浮心下降,可能會造成 GM(重心和穩心之間的距離)為負,導致船體失去穩定,出現劇烈橫搖甚至翻船的危險。這種情況主要發生在船隻騎在浪頭上時,當 GM 為負時，船體會繼續橫搖。

總之,船隻在風浪中的穩定性是一個複雜的問題,需要考慮船體結構、貨物分佈、波浪狀況等多方面因素。船舶設計和裝載時，都要充分考慮這些因素,以確保船隻在惡劣海況下，也能保持良好的穩定性。
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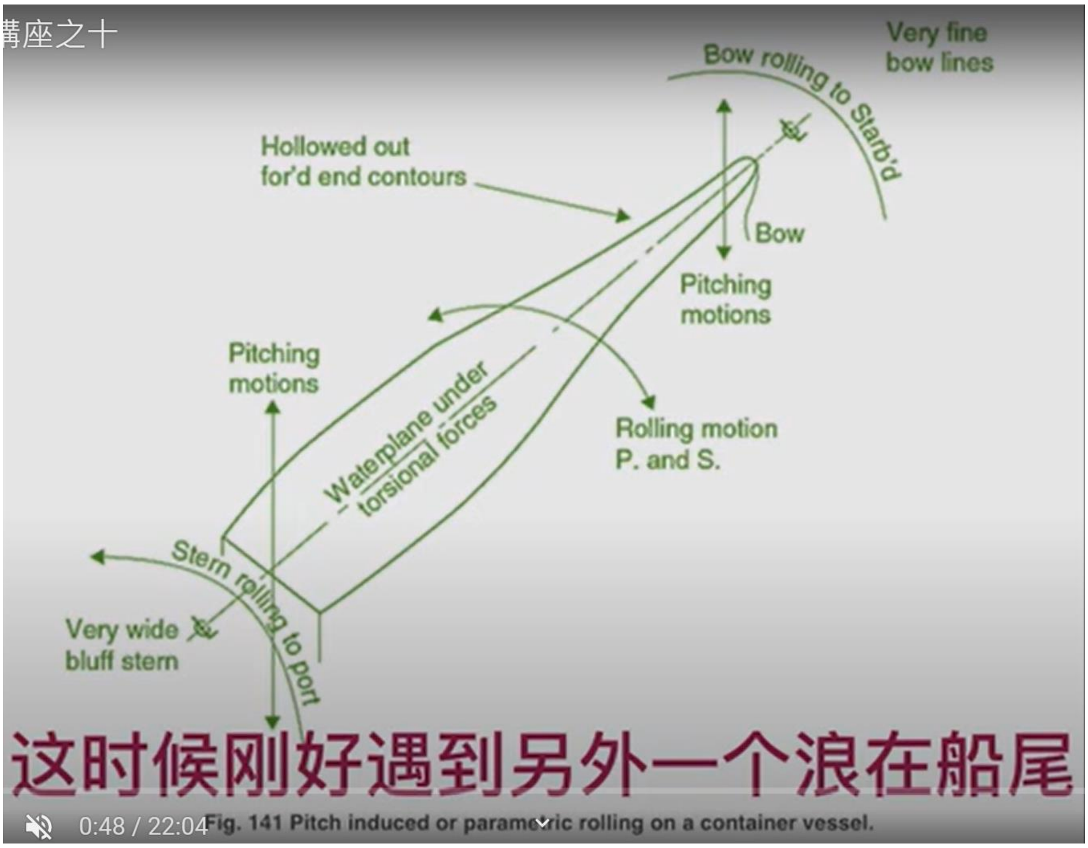
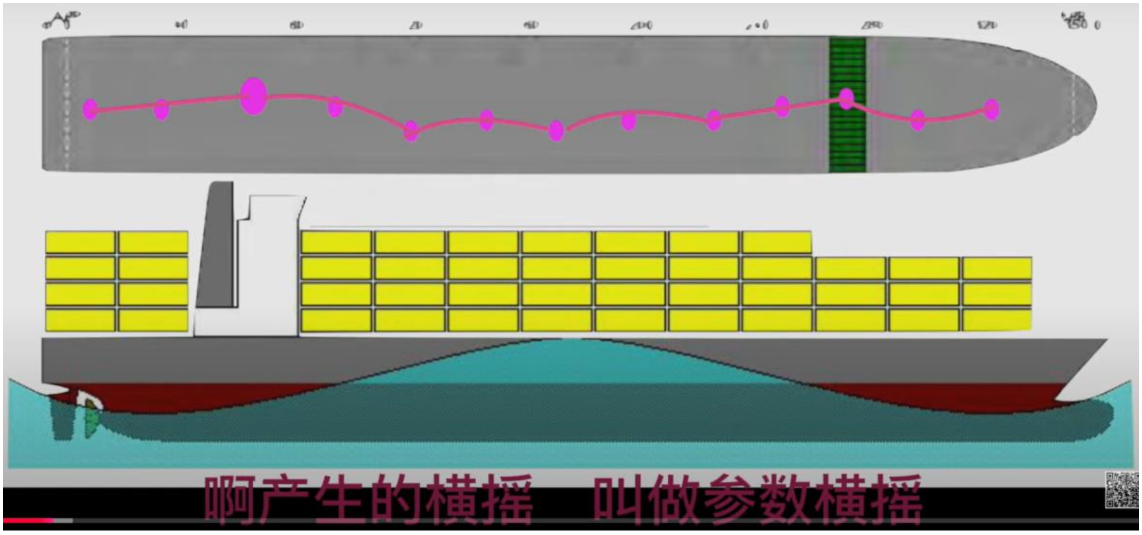
看這邊參數橫搖的示意圖(FIG.141)是表示，參數橫搖產生的情形是在船頭頂浪航行，尖形船頭的被前面的浪抬起來，如果有向右橫搖的趨勢，這時候剛好遇到另外一個浪在船尾，這個浪頭把圓形船尾也抬了起來，但是，圓形船尾的趨勢是什麼，向左橫搖，所以船頭向右，圓形船尾向左，船隻，就忽然就是被加速向右甩，產生的橫搖叫做參數橫搖。

如果像它這樣子解釋的話，應該所有的船吃到船頭浪跟船尾浪同時作用的時候，就會有參數橫搖的產生，偏偏參數橫搖似乎是貨櫃船的獨家專利，連木材船，遇到的都不多，所以，我提出來研究是因為這個浪，從船頭移動到船尾的時候，造成船隻的浮力的改變，所以船就搖晃的越來越厲害。

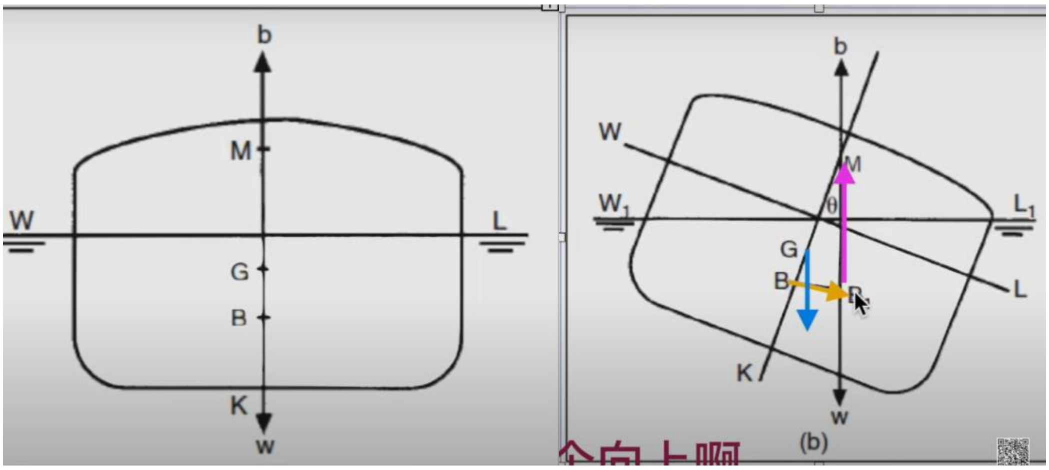


其實，如果跑過貨櫃船或是做過排艙或是做過排艙/調過壓艙水，應該都知道貨櫃船，看起來裝的滿，其實裡面的貨重是非常不平均的，假設一個浪打過來在第 12 bay，浪頭在 12bay 的時候，12 bay 的貨重是左邊重，這個浪頭造成船隻向左橫搖。然後等它浪過去到 16 bay，16 bay 的貨重是右邊重，就會造成船隻向右橫搖。或者是連續三個 bay 都是左邊重，再過去後面三個 bay 右邊重，所以這個浪頭，一過去的時候船隻的重心，因為波浪的浮力變化，就忽左忽右橫搖，這個就產生第九種新的船隻運動，這個就叫做抖動。(第七種是同步橫搖，第八種是參數橫搖)



船的重心忽左忽右，就好像有人拿著搖籃用手亂晃，一下晃左邊/一下晃右邊，坐在搖籃裡面的人，就感覺到這個船的抖動非常厲害。當然這個抖動，如果時間久了，不幸又跟這個船頭

頂的浪同步的時候，就會產生參數橫搖。



現在來談一談在風浪之中穩定度的變化首先，還是由靜態靜水的穩定度來講解，船體泡在水線下的體積，提供它的浮力。這條 WL line 水平線就是水線，所以在這個 WL line 下面跟船體的外板圍起來的這一塊空間，就是它浮力的來源。浮力的體積的中心，就叫浮心叫 buoyancy Center (B)，G 是重心，M 是穩心(浮心 B 因波浪運動產生位置變動，其垂線通過船中心線的一點)。

下面這個一條船，尤其鐵殼船是很明顯的，船體浮在水上，加上很高的甲板，重心一定是高於在水裡面的體積，所以 G 是 Gravity Center 重心，這是在靜止的時候，重心有下面的浮力在支撐，船在靜水之中是保持平正的，當然這不是一定的，如果甲板上/還是船艙裡面貨裝的一邊重一邊輕，重心如果不在中線的話，船就不能夠平正。如果船在靜水之中，像現在是平正的話，這樣船的重心一定是在中心，跟船的浮心重合。浮心主要是船設計建造的時候(船殼形狀)決定的，船的重心是後來裝貨/裝水/還是其他的東西所決定的。

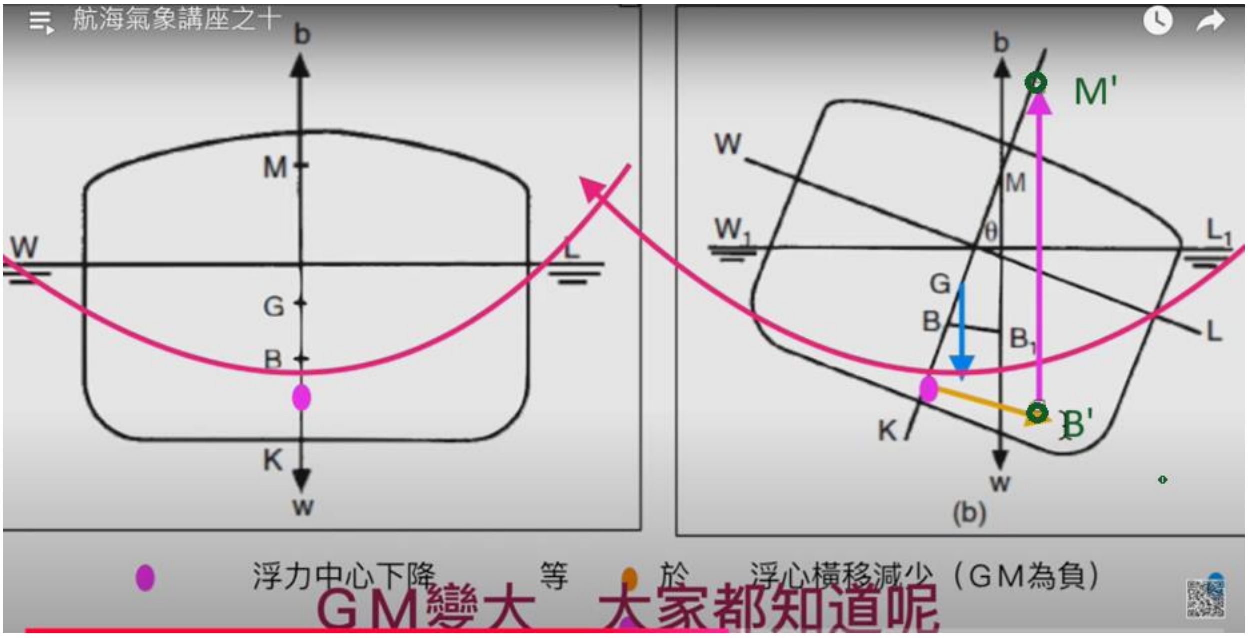
右邊看到船在傾側的時候，現在看新的水線(水平線)是 W_1 L_1，現在如果是從船尾向船頭看過去的話，我們看到的是船舯橫截面。這船現在是正在向右傾，船一向右邊傾斜的時候，左邊船體本來泡在水裡面，左邊的這一塊三角形區域(W O W_1)，本來泡在水裡面，現在，從左邊跑到右邊三角形區域(L O L_1)去了。所以新的浸水體積，改變了跟原來的長方形，造成浮心位置不一樣，從原來的中線向哪裡移動? 就移動到 B_1 的位置，B_1 就是新的浮心。

可是船上的貨並沒有動，所以重心還在原來的位置，重量一定是向著地球向下，浮力是向上，一個向下/一個向上，就有一個回正力臂 (G 點到 B_1M 線的垂直距離)。

我們看到船體右邊泡在新的水線 L_1W_1 下面的體積比較大，所以右邊的浮力比較大，左邊的浮力比較小，加上重心還在原來的船中繼續往下作用，船就有向左邊回正的力量，同樣的道理，船如果向左傾斜的時候，它也有一個回正的力量，讓它回到右邊，讓它保持平正。

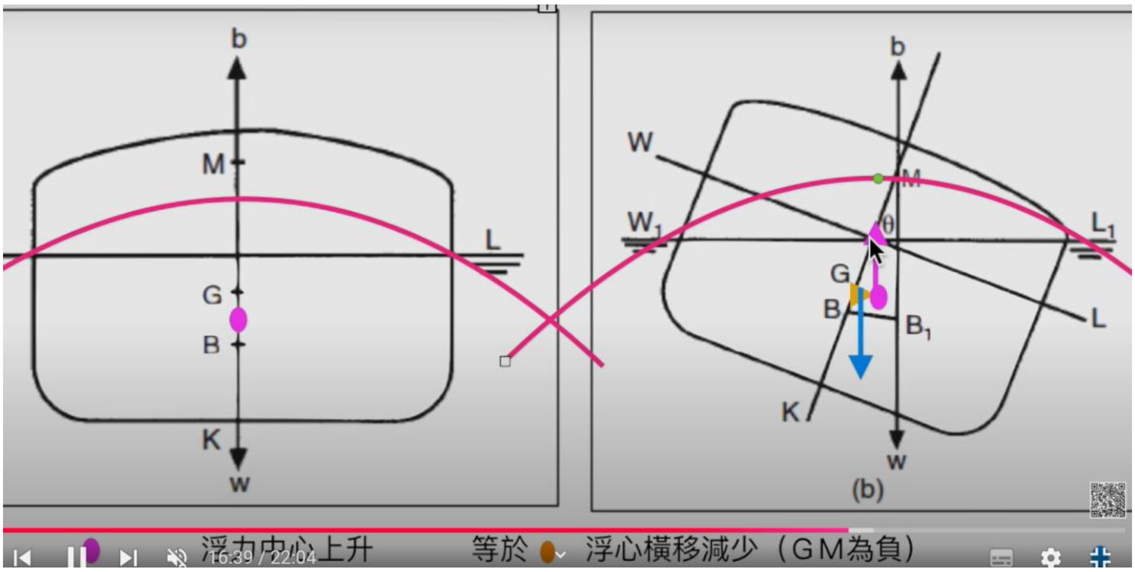
可是在有波浪的時候，看到像現在先拉一條水線下來，水線本來是水平的，所以叫做水平

線，現在是什麼 ？ 波浪型的水線。



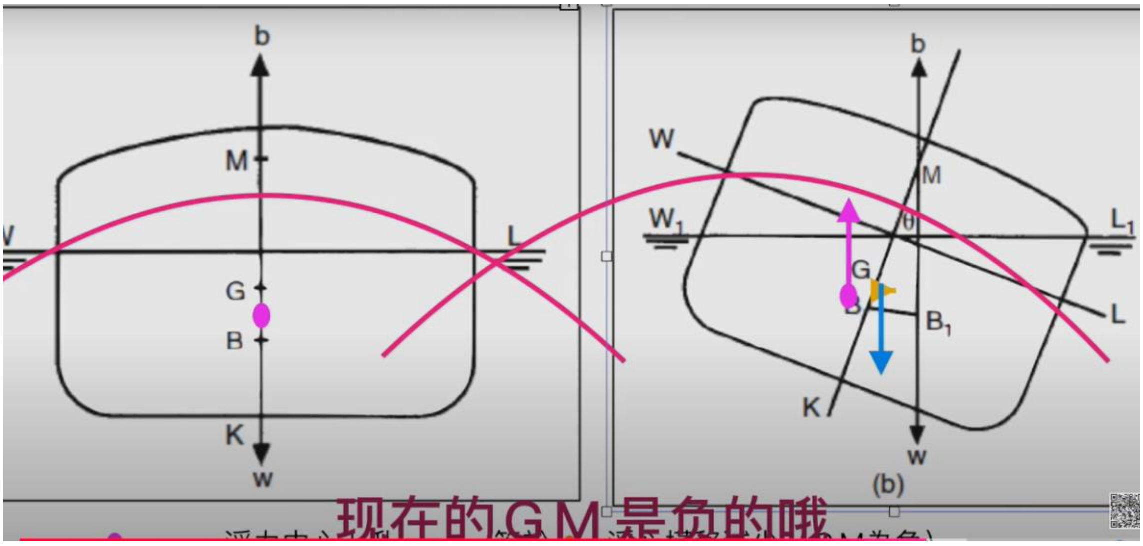
波浪，它在海裡面不是什麼平的，所以現在變成新的水線，就是這條紅線，加上它下面船體所圍住的體積，就是新的浮力來源，所以船怎麼樣? 船的浮心就變了。船的浮心下降，本來在這邊 B 的位置，因為現在這一部分的船體的水下體積變小了，所以浮心就跟著下降，如果它下降到粉紅點的位置，當然圖是畫得有點誇張，造成本來在 B 這邊的浮心下降，浮心下降以後，船同樣吃到波浪向右傾，它的浮心要向哪裡? B’

本來在靜水的時候，浮心是從 B 到 B_1，現在原來的浮心就已經下降，然後船再一傾側，根本這裡就沒有浮力了，因為它已經露在水面上了，因為船傾側這邊根本就沒有浮力，所以浮力可能再進一步的什麼? 下降。 浮心下降，可是浮心還是會向有浮力的地方位移，所以可能的位移是 B’ ，位移到位置，因為在這裡是泡在水下的體積中心，向上的箭頭代表它的浮力，本來浮力是通過向上的 M 點，叫做穩心。現在因為水下的體積變化，浮心反而越跑越遠，新的穩心 M’ 就越來越高，GM’ 比 GM 大，所以在波谷之中，GM 變大。GM 就是說重心跟穩心之間的距離，GM 變大，船的穩定度就好。這時候船會不會翻船啊? 不會，因為這裡雖然 GM’ 變大，但是什麼東西沒有變大，浮力沒有變大，因為泡在水裡面的體積其實是變小了，失去浮力，船身的重量隨然沒有變，在水面上的重量因失去支撐而變大，圖上波浪畫的是有些誇張，應該要向上修正一點。雖然 GM 變大，但是浮力變小，因為泡在水裡面的體積變小，所以一般來講，船如果是在波谷的話，是沒有什麼問題。



有問題的是什麼？船在波鋒之上，所以現在再回過頭來看看，船如果在波鋒之上，會是什麼樣的情形？剛剛已經看過，船體在波谷時穩定度的變化，現在來談一談比較複雜的船體，在波鋒的時候，穩定度的變化。首先，看到左邊這裡是船隻平正的時候，騎在波鋒上面的情形，水線本來是水平的，因為紅色的波浪產生一個弧度，造成船隻的什麼東西？浮心變化，本來在靜水的時候，浮心在下面。因為一個波浪來了，船在水裡面體積增加了，浮心就開始上移(紫紅色新的浮心)。

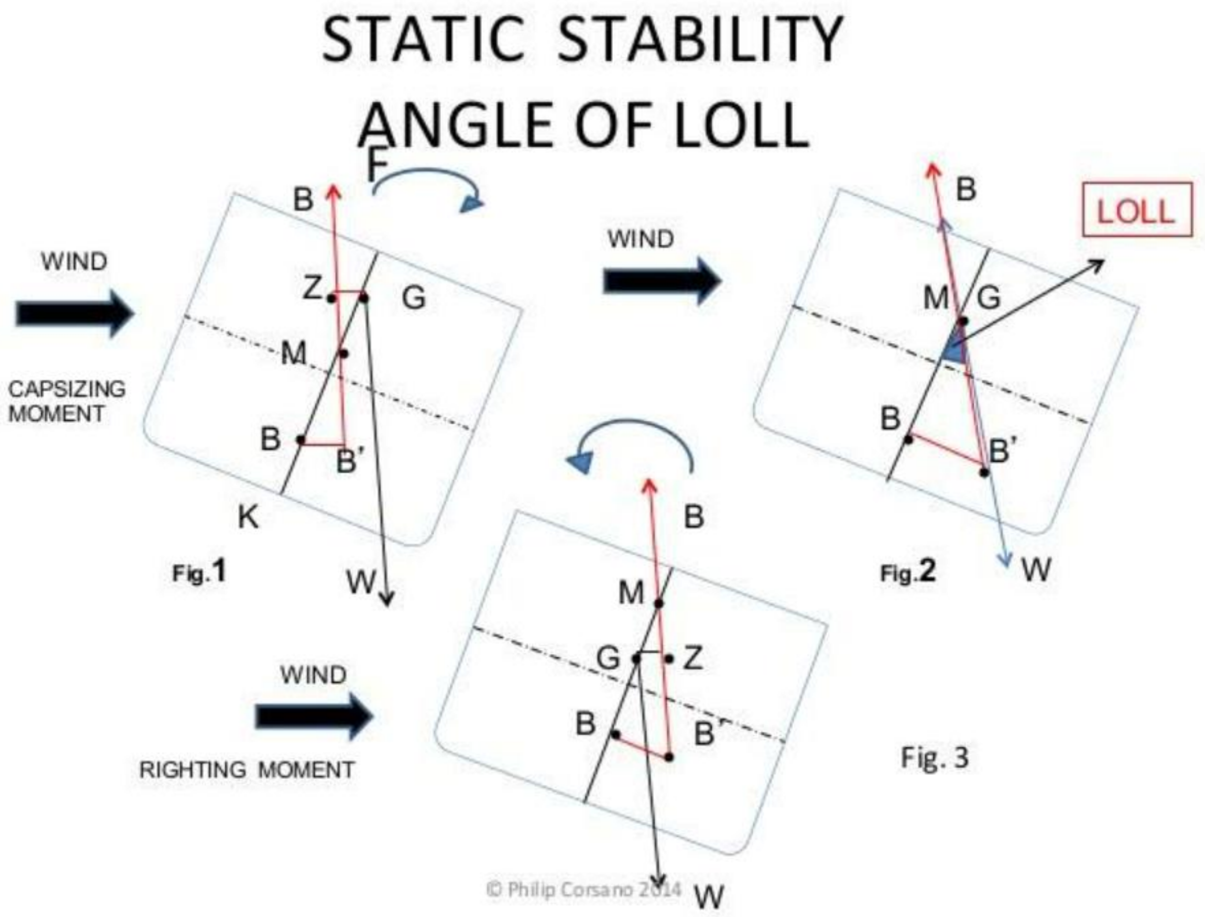
在波浪向右移動的時候(波鋒在船右舷的位置)，浮心因為左邊泡水的體積比較少，右邊泡水的體積比較多，所以新的浮心還是向右移動，右邊的紫紅色的浮心向上，左邊的藍色的重心向下，造成向左的浮正力矩，這是在理想的狀況，GM 還是保持正的，只不過可能浮心的變動不大，所以原來的 GM 是變小了。可是，不要忘記波浪不是永遠都不動的。



如果今天波浪是打到左邊，這裡看，現在船體泡在水裡面的體積，左邊不一定比右邊小喔，所以這時候浮心應該是在哪裡?它不但不見得會跑右邊，它還可能什麼？跑左邊。為什麼它要跑左邊啊？因為左邊船體泡在水裡的比較多嘛，看這是左邊船體泡在波浪裡面的，這是船體

右邊泡在波浪裡面的，時候的 GM 是什麼?

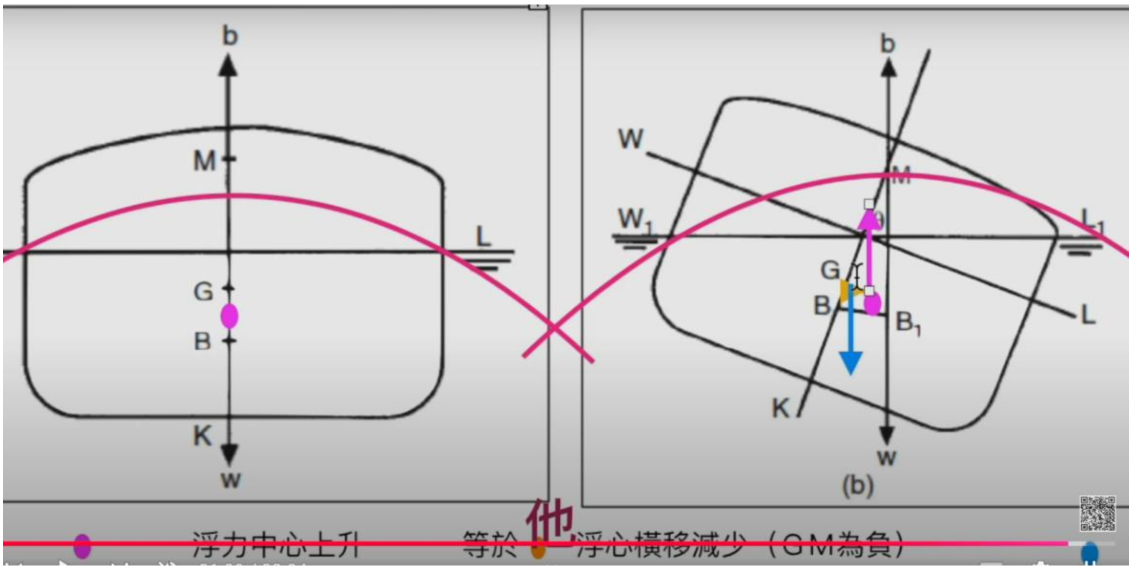
所以各位仔細看看，現在的 GM 是負的喔。因為船明明是向右邊偏了，可是怎麼樣? 重心還在右邊，浮心卻在左邊(左邊浪頭來了)，因為什麼左邊泡在水裡面的浮力比右邊的浮力大，浮心就在左邊，這是不變的定律。GM 為負的時候，會發生什麼事? 會翻船啊，因為船已經偏向右邊，又有一個力矩，把船體繼續向右邊推，船隻就會加速度搖動。



當然，這隨著波浪的運動變化，這可能是短時間的負 GM，不幸你的船剛好在浪頭最高的地方，船體本來如果向著右邊晃動，因為有左邊的浪頭上抬左舷，這時候船隻的搖擺，船身就會向右忽然大角度傾測，就會有一個大幅度的搖擺，造成 LASHING 過度負荷與斷裂，貨櫃隨之落海。

在 GM 為負的時候，船身也能平衡在一個特殊角度，這角度叫 ANGLE OF LOLL。事情發生在港裡面裝卸貨的時候，此時如果 GM 為負，然後一個 20 尺的貨櫃裝上去，船就直接就翻掉了，因為這就是負 GM 的影響，當然，這是一個以後的功課，可能在貨物裝載裡面，再做講解，這邊很明顯的看到，就是 GM 為負的時候，剛好你又在最高的大浪上面，你就翻掉了，不像漁船一樣翻掉了還有救，當然波浪是隨時在移動的，所以，現在滿街都在叫什麼參數橫搖，其實是什麼? 很可能是因為船騎在浪頭上面，GM 為負的時候，造成了劇烈的橫搖。

是航海穩定度比較合理的解釋，而不是莫名其妙的什麼參數橫搖，當然，參數橫搖時間是短暫的，看個人的運氣啊，



隨著波浪在變動，現在比較左邊跟右邊的浮心，就發現了浮心怎麼樣?又跑到右邊去了，這時候 GM 就又回正了，所以船遇到波浪過去，讓船一下有左傾的力矩，一下又有右傾的力矩，造成船隻不規則的擺動，好像魚在水裡面遊一樣，一下子偏左邊一下偏右邊，船就是這樣，是在海裡面游泳，尤其是越大的船高張力鋼的船就越明顯，船頭船尾不同步時，造成船身抖動。

So when we look at the illustration of parametric rolling here, it means that when the ship is rolling synchronously with the waves coming from the bow and the waves coming from the port and starboard sides of the ship, the ship experiences parametric rolling. As the ship sails through the waves with the bow lifted by the oncoming wave, if there is a tendency to turn to the right, and at that moment encounters another wave lifting the stern, but with the stern tending to turn to the left, the ship will suddenly be accelerated to the right and start rolling. This phenomenon is called parametric rolling. If explained in this way, parametric rolling occurs when both the bow and the stern of the ship are affected by waves simultaneously.
Parametric rolling seems to be more common in container ships and less so in timber ships. Therefore, the study was proposed because when the wave moves from the bow to the stern, it causes a change in the ship's buoyancy, resulting in increased rolling. Those of us who have worked on container ships or have experience in ballasting or deballasting would know that although container ships may appear fully loaded, the distribution of weight inside is actually uneven. For example, when a wave hits, at one moment the left side may be heavier at 12

times the wave height, then as the wave moves to the 16th wave height, the right side may become heavier, or there could be a pattern of three times heavier on the left and three times heavier on the right, causing the ship's center of gravity to shift unpredictably, resulting in a new type of ship motion known as rocking where the ship's center of gravity shifts abruptly from side to side. Some people may compare the ship's rocking motion to holding a cradle and shaking it randomly from one side to the other. The person sitting in the cradle would feel the ship's rocking motion very intensely. This rocking motion, if unfortunately synchronized with the waves hitting the ship's bow, can lead to parametric rolling. Now let's talk about the changes in stability in wind and waves. First, let's start by discussing static stability in calm waters. We know that the volume of the ship's hull submerged in the water provides its buoyancy. The WL line represents the waterline, and the space enclosed by the hull's outer plating below this WL line is the source of buoyancy. The center of buoyancy volume is called the centroid or BBorne Center.

It is evident in ships, especially in iron-hulled ships, that the ship floats on the water with a high deck, so its center of gravity is higher than the volume submerged in water, which is the Gravity Center or center of gravity. When the ship is at rest, the center of gravity is supported by the buoyancy below, keeping the ship upright in calm waters. However, if the weight distribution on the deck or inside the ship is uneven, the center of gravity will shift, causing the ship to become unstable. If the ship is properly balanced in calm waters, the center of gravity will align with the centroid or buoyancy center. The ship's buoyancy center is mainly determined during the ship's design and construction, based on whether cargo, ballast, or other items are loaded at the rear or elsewhere in the ship.

Observing the waterline during a stability test, now if we look at this WL Line as W1 L1, then if the ship is in... If we look from the stern to the bow of the ship, we are looking at the part of the ship, the cross-section of the ship. When the ship is tilting to the right, the triangular area on the left side of the ship's hull that was originally immersed in water is now shifted from the left to the right. Therefore, this new submerged volume changes the metacentric height differently from before, moving from the original centerline in direction B to position B1. This is the new metacentric position. The cargo on the ship has not moved, so the center of gravity remains in its original position.

The weight must act downwards towards the earth, buoyancy is upwards and downwards, resulting in a righting moment. If we see that the volume of the right side of the ship's hull submerged below the L1 W1 line is larger, the buoyancy on

the right side is larger than on the left, and with the weight still acting downwards in the original ship, there is a force to the left for righting. The same applies if the ship tilts to the left, there is a force for righting it to the right to maintain stability. When there are waves, the waterline is no longer horizontal but adjusts to the waves, creating a new waterline. This change affects the position of the ship's center of buoyancy, causing it to descend. The drawing may be exaggerated, but the concept is the same.
As the center of buoyancy descends, the ship encounters the waves and tilts to the right, with the center of buoyancy shifting from B to B1. Now, the original center of buoyancy has already decreased, and the ship eventually reaches a point where there is no buoyancy in this area, resulting in further descent of the center of buoyancy. However, there is still displacement where there is buoyancy, so the possible displacement occurs due to the change in underwater volume. The upward arrow represents buoyancy; originally, the buoyancy at point M, known as the metacentre, is upwards. Due to the change in underwater volume, the metacentre shifts farther away. The distance between the center of gravity (G) and the metacentre (M) increases, enhancing stability.
Despite the increase in the metacentric height, the ship will not capsize because there is a substantial distance between the center of gravity and the metacentre. Although the metacentric height increases, the buoyancy decreases because the submerged volume in water actually decreases. Generally speaking, if the ship is in the waves, there is usually no problem with the ship in the waves, what is problematic is the ship above the waves, so let's go back and look at what the situation will be like if the ship is above the waves. We just saw the change in stability of the hull in the waves, now let's talk about the more complex change in stability of the hull in the waves. Let's talk about it now.
First, we see here on the left side the situation of the ship riding on the waves when the ship is upright, the waterline was originally horizontal, but because of the waves, this red wave creates a curvature, causing something on the ship to what floats, initially when it enters the water, with a wave coming in, the volume in the water increases, causing the float to start moving upward. Then, we see that if the float starts moving upward, like this when the waves are calm, the float, because the volume of water on the left side is less than on the right side, so the float moves to the right, causing the float to move up and the right side's purple float up and the left side's blue center of gravity down, causing a leftward float momentum.
This is ideal condition GM is still maintained, but the variation of the float is not significant, so the original GM has decreased, but we must not forget that

the waves are not always still, if the waves today only reach this point, then we see, now the volume of the hull in the water, the left side is not necessarily smaller than the right side, so at this time, where should the float be, it may not necessarily run away, not only might not run to the right, it may run to the left, why does it run to the left, because the left side of the hull is in the water more, we see the left side
submerged in the hull, the right side submerged in the hull, what is the GM at that time, so everyone look carefully now the GM is negative, because the ship clearly leans to the right but the center of gravity is still on the right, the float on the left side submerged in the water is larger than the float on the right side, the right side is larger, the left side is smaller. The float is on the left side, this is definitely unchanged, what will happen when the GM is negative, will it be unstable, will the ship capsize, so the ship has already leaned to the right, and there is a torque that pushes it to
the right, of course, with the movement of the waves, this may be temporary, unfortunately, your ship happens to be at the highest point of the wave, now because there are no waves here, if the hull is sliding to the right at this time, the sway of your ship's bow will suddenly increase, there will be a large deviation, when the GM is negative, the balance point of the ship has a special term that slides over, this in the terminal when loading and unloading, the GM is negative, and then a 20-foot container goes down, the ship will directly capsize, because of this negative GM effect, of course, this is a lesson for the future may, we
will explain in the loading of cargo, it is very obvious here, when the GM is negative, if you happen to be on top of the highest wave, then you will capsize, unlike fishing boats, there is help, of course, the waves are always moving, this wave may also go by, so now everyone is talking about what is called parametric rolling, it is likely because the ship is riding on the crest of the wave, causing severe rolling when the GM is negative, that This is a more reasonable explanation of what our rescue agency is talking about here, instead of inexplicable parameter oscillation. Of course, this time is just a brief moment of luck for individuals. As the wave passes by, we are comparing the left and right floating stars, then we discovered how the floating stars move, shifting to the right. At this point, the GM corrects it, so the ship, as the wave passes, causes the ship to experience a sudden moment of port and starboard torque, resulting in the irregular swinging of the ship, as if a fish is swimming in the water, suddenly veering left and then right. That's how the ship is, swimming in the sea, especially larger ships with high tension steel hulls, showing the

effect more prominently.