Study on the Economic Feasibility of an Underwater-Sill (UWS) Development for Sediment Countermeasure at Patimban Port’s Navigation Channel

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Abstract. A new international seaport is under construction at Patimban area of Subang Regency, West Java, Indonesia. This Port’s navigation channel runs from the position of –6m LWS to –17m LWS of the existing depth with total length of 3,762 m. The original design considers that the existing sedimentation rate is low along the channel. The Cipunagara River which shows continuous delta expansion of about 1.00m to 1.25m toward navigation channel. In reference to the successful application of Underwater-sill (UWS) structure in controlling the siltation rate into the navigation channel of Kumamoto Port in Japan and Tuban Port in East Java Indonesia, the possible application this type of structure was carried out. The calculation has resulted that installation of UWS with height of 1.0 m, 1.5 m, 2.0 m, and 4.0 m respectively decrease the sedimentation rate to be 0.09 m per year, 0.06 m per year, 0.022 m per year and 0.022 m per year. The present economic feasibility study concluded that 2m height UWS which is designed for minimum service life of 30 years with development interest rate at 10 percent per year and an annual inflation rate at 10% gives the most economic investment.

1. Introduction
Patimban Port was built in Patimban area, Subang Regency with a long cruise line from a depth of minus 6 m to minus 17 m with a length of 3,762 m. For the pool area is planned to be protected with a breakwater that is not overtopping, so that the anchor pool area is spared from sedimentation. On a long cruise line with no protection, it is an area prone to sedimentation. Therefore, sediment control buildings are necessary. The sediment control building was planned in the form of underwater sill (UWS) buildings as once made in Kumamoto Japan and Tuban Port of East Java.

The construction of UWS in Kumamoto, based on research conducted, can be estimated that UWS with a height of 1.0 m can prevent superficiality in Kumamoto Port - Japan about 30% of the total sedimentation produced without UWS. Based on the measurement of the sediment deposition field in Tuban Port in 2002, where UWS building was built in 2000, shows that UWS Building in Tuban is effective enough to withstand sediment rate between 60 to 83 percent.
1.1 Research on UWS

Research related to the utilization of UWS for the protection of anchor pools from the superficiality has been done by several researchers among others (research conducted in Japan): [1-3]. Based on Tsuruya has conducted research using a mathematical model (Finite Difference Method), with the main study being calculating transport sediments that can be withheld by UWS [1]. From the results of his research, it can be estimated that UWS with a height of 1.0 m can prevent superficiality in Kumamoto Port - Japan about 30% of the total sedimentation produced without UWS. Meanwhile, conducted field research by observing and analyzing long-term bathymetry survey data to determine the effectiveness of UWS installation [2]. From the observations made it can be concluded that UWS is indeed able to reduce the sediment that enters the anchor pond. According to Hidayat, also researching with physical models, brought the higher UWS the more effective in sedimentation control that goes into the anchor pond or shipping groove [3]. In Indonesia, several studies related to UWS have been conducted, including by Bhakty and Peppy 5 (see Figure 1). According to Bhakty research conducted UWS research in two ways, namely by conducting physical model tests and mathematical model tests [4]. Physical model research was conducted in wave pools, Hydraulic Laboratories, Department of Civil and Environmental Engineering, Faculty of Engineering, Gadjah Mada University Wave Channel, Center for The Study of Engineering, Gadjah Mada University. Research in wave pools to obtain a distribution of the flow speed of the beach in the direction of the sea (perpendicular to the beach), while the research conducted in the wave channel is aimed at knowing the distribution of vertical direction of the water speed at the location affected by UWS. Research in this wave channel is primarily aimed at obtaining data that will be used for calibration and verification of mathematical models to be developed for research purposes. From both models, a method of calculation approach is made or an estimate of the rate of superficiality that occurs in the anchor pool due to protection with underwater sill (UWS). complements the estimated method of anchor pool superficiality developed by Peppy and Bhakty [4-5] by adding a beach slope variable.

1.2 Construction of UWS In Semen Gresik Tuban Port

The construction of UWS at Gresik cement port in Tuban was carried out by PT Semen Gresik in 2000. The UWS development was built to protect the anchor pond from sediment superficiality. UWS structure is made of reinforced concrete material with a length of 6 m, width of 6 m, and height of 2 m with a thickness of 20 to 30 cm. UWS structure is installed on the seabed with the previous place of place in the foundation of bamboo stake with a depth of 6 m.

To find out the work of UWS installation in Tuban Port was done measuring bathymetry at the location of shipping flow, rotary pool, and anchor pool/pond in March 2000, which was the initial condition after UWS was built. After that successive measurements were taken in December 2000, May 2001 and May 2002. Based on the measurement results, sediment deposits are calculated and compared to theoretical sediment counts. Sediment results as in Table 1. From the data after the count, the thickness of sediment deposits in Tuban port as presented in Table 2.

| Location     | Theoretic (per year) | March 2000 | December 2000 | May 2001 | May 2002 |
|--------------|----------------------|------------|---------------|----------|----------|
| Navigation Channel | 0.8                  | 0.25       | 0.31          | 0.63     | 0.88     |
| Turning Basin  | 1.5                  | 0.69       | 0.82          | 0.95     | 1.2      |
| Basin         | 1.5                  | 1.33       | 1.45          | 1.5      | 1.9      |
Table 2. Sediment deposits at Tuban Port take 1 and 2 years

| Location     | Theoretic (per year) | March 2000 - May 2001 (1 year) | March 2000 - May 2002 (2 years) |
|--------------|----------------------|--------------------------------|---------------------------------|
| Navigation   | 0.8                  | 0.63 – 0.25 = 0.38             | 0.88 – 0.25 = 0.63              |
| Turning Basin| 1.5                  | 0.95 – 0.69 = 0.26             | 1.2 – 0.69 = 0.51              |
| Basin        | 1.5                  | 1.5 – 1.33 = 0.17              | 1.9 – 1.33 = 0.57              |

From the data seen that in the shipping flow there is a yearly deposition of 0.38 m and 2 years of 0.63 meters or an average annual 0.315 m. Based on theoretical counts there will be a deposition of 0.8 m per year. It can be said that UWS Building can prevent sedimentation (100-0.315/0.8 × 100) percent equal to 60.625 percent. In the year-end rotary pool of 0.26 m, after 2 years there is a deposition of 0.51 m or an average deposition of 0.255 per year. Based on the theoretical count of precipitation that occurs in the rotary pool of 1.5 m per year. UWS buildings can prevent sedimentation in rotary pools by (100-0.255/1.5 ×100) percent equal to 83 percent.

1.3 UWS building materials and shapes

The UWS building is shaped like an inverted T, made of reinforced concrete printed on land. The building is placed on the seabed with a bamboo niche foundation. The building is generally in the water and not visible except by diving. UWS image as in Figure 1.

![UWS Image](image)

Figure 1. UWS Image

2. Numerical study results

Based on Wibowo numerical studies, the table can be explained that with the higher UWS, the less thickness of sedimentation that occurs [6]. Therefore, it is necessary to determine the height of UWS which provides the most optimal benefits and costs.

Table 3. Thickness of sedimentation in navigation channel

| No | Structure | Sediment (m) |
|----|-----------|--------------|
| 1  | Without UWS | 0.110        |
| 2  | UWS 1 m    | 0.088        |
| 3  | UWS 1.5 m  | 0.060        |
| 4  | UWS 2 m    | 0.022        |
| 5  | UWS 4 m    | 0.022        |
With a shipping flow length of 3,762 m and a lower flow width of 380 m, the volume of sedimentation in the cruise line can be calculated. The result of the sedimentation volume count can be seen in the table.

![3,762 m length](image)

**Figure 2.** Image of the location and position of the building Under Water Sill (UWS)

| No | Structure   | Yearly Sedimentation (m) | Navigation Channel (m) | Yearly sedimentation volume (m³) |
|----|-------------|--------------------------|------------------------|----------------------------------|
| 1  | No UWS     | 0.11                     | 3,762                  | 157,501                          |
| 2  | 1 m high UWS | 0.09                 | 3,762                  | 125,341                          |
| 3  | 1.5 m high UWS | 0.06            | 3,762                  | 86,336                           |
| 4  | 2 m high UWS | 0.02                   | 3,762                  | 32,079                           |
| 5  | 4 m high UWS | 0.02                   | 3,762                  | 31,548                           |

**Table 4.** Sedimentation volume in the navigation channel

3. **Economic studies**

For the optimization of UWS building dimensions in Patimban, which can provide optimum value, economic studies will be conducted. In this study, some assumptions are prevalent and accountable. The cost for the construction of UWS is as in the following table.
Table 5. UWS Patimban Construction Costs

| Construction  | 1 m UWS | 1.5 m UWS | 2 m UWS | 4 m UWS |
|---------------|---------|-----------|---------|---------|
| Cost (Rp)     | 92,652,213,500 | 101,776,684,500 | 159,192,890,400 | 238,174,223,300 |

The construction of UWS in Patimban, serves to reduce the rate of sedimentation. With the building, sedimentation will be reduced compared to the construction of UWS. To know the effectiveness of the construction of each UWS or not built UWS will be done the cost of development plus dredging costs. Building life is simulated 20 years and 30 years, dredging price per cubic meter Rp 85,000, for 2020, while the price of the following year will be adjusted to the inflation rate. UWS's initial construction costs will be carried out with the loan funds and will be refunded over the life of the plan in even installments.

The comparison of construction costs and dredging costs will be used net present value (NPV) method which is the expected cash flow in the future which is discounted at this time. To calculate NPV, data on estimated investment costs, operating costs, and maintenance is required. In this article the cost of investment is the initial cost of construction and the cost of maintenance operations is the cost of dredging. According to Kasmir Net Present Value (NPV) or net value is now a comparison between Present Value (PV) net cash and Investment PV during the investment life [7]. The equations used are:

\[
NPV = \sum_{i=1}^{n} \frac{\text{values}_i}{(1 + \text{rate})^i}
\]

Where i is interest and n is lifetime.

The result of the investment and maintenance costs of each UWS, once taken into account against NPV will be compared to each other. The lowest cost of UWS is the cheapest and most efficient type of building. In addition, it can also be analyzed with the cost of development and dredging without UWS development in making zero. The cost of each UWS is the cost without UWS building at the cost of each UWS. For UWS which has the larger cost difference and positive is UWS that is worth building.

The count of construction and maintenance costs of dredging for each UWS for interest rate is 7.5% per year and inflation is 4.76% as in the following table.

Table 6. NPV count investment costs and dredging costs at the Navigation Channel in Patimban (in Million Rupiah)

| Year | NO UWS | 1 m UWS | 1.5 m UWS | 2 m UWS | 4 m UWS |
|------|--------|---------|-----------|---------|---------|
|      | Dredging | Instalment | Dredging | Instalment | Dredging | Instalment | Dredging | Instalment | Dredging | Instalment |
|      | 204,449 | 204,449 | 91,061 | 99,134 | 126,522 | 161,478 |
| 2025 |         |         |         |         |         |         |
| 2030 | 72,467 | 78,891 | 100,688 | 125,506 |
| 2035 | 74,122 | 61,768 | 61,768 | 61,768 |
| 2040 | 81,421 | 67,851 | 67,851 | 67,851 |
|      | 279,802 | 162,702 | 92,652 | 117,100 | 49,916 | 54,341 | 69,355 | 74,122 | 61,768 |
|      | 117,100 | 92,652 | 74,122 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 |
| 1.5 m UWS | Dredging | Instalment | 240,704 | 112,071 | 49,916 | 54,341 | 69,355 | 88,516 | 117,100 | 92,652 | 74,122 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 | 61,768 |
|      | 128,632 | 101,777 | 81,421 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 | 67,851 |
| 2 m UWS | Dredging | Instalment | 242,840 | 41,641 | 18,547 | 20,191 | 25,769 | 32,889 | 201,199 | 159,193 | 127,354 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 |
|      | 201,199 | 159,193 | 127,354 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 | 106,129 |
| 4 m UWS | Dredging | Instalment | 341,973 | 40,952 | 18,240 | 19,857 | 25,343 | 32,345 | 301,021 | 238,174 | 190,539 | 158,783 | 158,783 | 158,783 | 158,783 | 158,783 | 158,783 | 158,783 | 158,783 |
3.1. UWS 20 years lifetime

The life of the building can be planned for a certain period of time e.g., 20 years, 30 years or 50 years. Shorter building life is generally cheaper and construction is relatively easy compared to longer building life. Summary of dredging costs in Patimban shipping line for a period of 20 years, both dredging because it was not built UWS and dredging costs and construction costs if built UWS presented in Table 7.

Table 7. Total cost value of UWS installation with and not UWS installation for 20-year plan life with interest rate and inflation varying

| Condition          | NO UWS   | UWS 1M   | UWS 1.5 M | UWS 2M   | UWS 4M   |
|--------------------|----------|----------|-----------|----------|----------|
| 3% Interest, 1% Inflation | 225,935,148,088 | 294,060,011,162 | 338,183,648,316 | 275,337,245,780 | 371,429,803,821 |
| 6% interest, 1% inflation | 170,688,140,632 | 255,731,532,944 | 225,268,865,869 | 240,768,151,272 | 342,398,643,759 |
| 10% interest, 1% inflation | 123,979,156,886 | 218,861,773,547 | 199,996,089,491 | 231,773,003,626 | 333,818,034,677 |
| 1% inflation, 3% interest | 333,078,618,303 | 379,325,700,826 | 308,092,547,303 | 264,156,639,798 | 360,434,178,687 |
| 6% inflation, 5% inflation | 241,638,485,393 | 312,194,423,923 | 264,161,213,061 | 255,218,935,558 | 356,610,342,764 |
| 10% inflation, 5% inflation | 166,951,933,673 | 253,059,876,727 | 223,552,171,709 | 240,525,467,474 | 342,425,690,794 |
| 3% inflation, 6% interest | 569,547,194,548 | 567,509,415,584 | 437,715,849,320 | 312,319,286,466 | 407,799,984,180 |
| 10% inflation, 6% interest | 393,871,494,932 | 433,342,754,491 | 347,609,702,014 | 286,224,935,450 | 387,103,354,707 |
| 10% inflation, 7% inflation | 255,581,738,013 | 323,592,232,797 | 272,135,742,846 | 258,577,108,916 | 360,178,671,508 |
| 7,5% inflation, 4,76% inflation | 203,436,005,756 | 282,500,113,138 | 243,997,259,988 | 248,653,754,719 | 350,777,044,830 |

Table 8. Difference in dredging costs without UWS reduced by UWS investment and dredging, with 20-year plan age

| Condition          | 1 m UWS   | 1.5 m UWS | 2 m UWS | 4 m UWS   |
|--------------------|-----------|-----------|---------|-----------|
| 3% Interest, 1% Inflation | -         | -         | 49,402,097,692 | 145,494,655,733 |
| 6% interest, 1% inflation | -         | -         | 70,080,010,640 | 171,710,503,127 |
| 10% interest, 1% inflation | -         | -         | 107,793,846,740 | 209,838,877,791 |
| 1% inflation, 3% interest | -         | 24,986,071,000 | 68,921,978,505 | 27,355,560,383 |
| 6% inflation, 5% inflation | -         | -         | 22,522,727,668 | 114,971,857,371 |
| 10% inflation, 5% inflation | -         | -         | 56,600,238,036 | 175,473,757,122 |
| 5% inflation, 6% interest | -         | -         | 131,831,345,22 | 161,747,210,368 |
| 10% inflation, 6% interest | -         | -         | 46,261,792,918 | 6,768,140,225 |
| 7,5% inflation, 4,76% inflation | -         | -         | 16,554,004,833 | 104,596,933,494 |
| 10% inflation, 7% inflation | -         | -         | 203,778,964 | 147,341,039,073 |
The cost of development and dredging for the life of the UWS plan is 20 years, can be explained as follows. For interest rates ranging from 1 to 10% per year, with a small inflation of 1 to 5% UWS development will be more expensive than not building UWS but treatment with dredging. UWS development will be effective and efficient if the loan interest rate is relatively small compared to inflation. This can be seen at the 3% interest rate and the 5% inflation, UWS development is more efficient. In addition, at the time of loan interest rate up to 6% per year, but inflation higher than 10% UWS will also be effective. For a 20-year building age plan it will be effective if the loan interest rate is smaller than inflation. For UWS development which is from UWS height of 1m, 1.5 m, 2 m and 4 m, the most effective and cost-effective in terms of investment and dredging is UWS type height of 2 m.

**20 Years UWS lifetime**

![Graph showing costs](image)

**Figure 3.** UWS's total operating costs in the shipping line with variations in inflation and annual bank interest for the life of the 20-year plan

3.2. **UWS 30 years lifetime**

Summary of dredging costs in Patimban shipping line for a period of 30 years, both dredging because it was not built UWS and dredging costs and construction costs if built UWS presented in Table 9 and Table 10.
### Table 9. Total cost value of UWS installation with and not UWS installation for 30 years plan life with interest rate and inflation varying

| Condition                  | NO UWS | 1 m UWS | 1.5 m UWS | 2 m UWS | 4 m UWS |
|----------------------------|--------|---------|-----------|---------|---------|
| 3% Interest, 1% inflation  | 304,893,916,866 | 359,999,170,683 | 296,051,431,316 | 263,747,799,718 | 362,765,546,977 |
| 6% interest, 1% inflation  | 207,881,647,509 | 285,886,319,713 | 246,267,585,846 | 249,298,617,815 | 351,277,633,508 |
| 10% interest, 1% inflation | 138,201,334,689 | 227,082,010,462 | 204,389,182,743 | 229,346,970,797 | 328,703,278,595 |
| 3% interest, 5% inflation  | 545,650,706,963 | 551,595,482,689 | 428,025,373,102 | 312,783,846,699 | 410,990,302,554 |
| 6% interest, 5% inflation  | 340,855,430,537 | 391,707,993,159 | 319,158,881,221 | 276,382,002,126 | 377,912,928,746 |
| 10% interest, 5% inflation | 204,448,722,046 | 279,802,247,729 | 240,703,543,135 | 242,839,882,035 | 341,972,952,367 |
| 3% interest, 10% inflation | 1,277,080,967,559 | 1,133,673,937,72 | 828,968,310,551 | 461,757,624,791 | 557,499,339,846 |
| 6% interest, 10% inflation | 720,509,270,093 | 693,839,764,680 | 527,271,033,323 | 353,707,852,440 | 453,959,438,624 |
| 10% interest, 10% inflation| 377,287,327,543 | 417,348,687,736 | 335,447,255,456 | 278,042,718,790 | 376,593,365,361 |
| 12% interest, 9% inflation | 253,924,866,064 | 309,506,484,654 | 257,202,987,269 | 236,303,346,503 | 327,027,103,138 |
| 7.5% interest, 4.76% inflation | 269,141,577,134 | 333,796,318,317 | 278,923,989,893 | 260,330,419,372 | 361,385,943,064 |

### Table 10. Total cost value of UWS installation with and not UWS installation for 30 years plan life with interest rate and inflation varying

| Condition                  | 1 m UWS | 1.5 m UWS | 2 m UWS | 4 m UWS |
|----------------------------|---------|-----------|---------|---------|
| 3% Interest, 1% inflation  | -       | 8,842,485,550 | 41,146,117,148 | 57,871,630,111 |
| 6% interest, 1% inflation  | -       | 38,385,938,337 | 41,416,970,306 | 143,395,985,999 |
| 10% interest, 1% inflation | -       | 66,187,848,053 | 91,145,636,107 | 190,501,943,906 |
| 3% interest, 5% inflation  | -       | 117,625,333,861 | 232,866,860,263 | 134,660,404,049 |
| 6% interest, 5% inflation  | -       | 21,696,549,316 | 64,473,428,411 | 37,057,498,209 |
| 10% interest, 5% inflation | -       | 36,254,821,089 | 38,391,159,989 | 137,524,230,320 |
| 3% interest, 10% inflation | -       | 448,112,657,008 | 815,323,342,768 | 719,581,627,713 |
| 6% interest, 10% inflation | -       | 193,238,236,770 | 366,801,417,653 | 266,549,831,468 |
| 10% interest, 10% inflation| -       | 41,840,072,087 | 99,244,608,754 | 693,962,182 |
| 12% interest, 9% inflation | -       | 3,278,121,204 | 17,621,519,561 | 73,102,237,074 |
| 7.5% interest, 4.76% inflation | -       | 9,782,412,759 | 8,811,157,762 | 92,244,365,930 |
Figure 4. UWS's total operating costs in the shipping lanes with variations in inflation and annual bank interest for the life of the 30-year plan

The cost of development and dredging costs for UWS with a plan lifespan of 30 years, can be explained as follows. The result of the UWS development cost count coupled with the 30-year cost of noise for UWS type is effective and efficient is UWS height of 2 m. UWS development is 2 m high when compared to not built UWS, providing an advantage if built UWS. For loan interest rate of 3% and inflation of 1% development UWS 2m will get an accrued profit of 41.16 M. For 6% annual interest rate and 5% inflation per year, UWS high 2 m development will be benefited 64.47 M. UWS development for interest rates starting from 6% and above with inflation of 1%, UWS development in Patimban is less feasible, because it provides greater costs than not building UWS. For loan interest rates smaller than 10% per year, and with inflation greater than 5%, UWS development with a height of 2 m is worth building. The development will provide a smaller cost than UWS did not build. For UWS development with a height of 1 m, 1.5 m, 2 m and 4 m, the most effective and cost-effective in terms of investment and dredging is UWS type height of 2 m.

4. Conclusion
Construction of sediment control building by using Under Water Sill (UWS) structure at Patimban Port shipping line can reduce sedimentation rate into the shipping flow. The feasible development plan of UWS is appropriate for 30 years design life and the 2m height of UWS will provide the most advantage or the most feasible dimension. Economic study of UWS development on the bank interest rate of 7.5% per year and with an average inflation of 4.76% per year has shown to be feasible and profitable. The 12% annual rate with inflation of 9% per year provides a profit of 17.62 M, whereas under an interest rate of 10 percent per year and an inflation rate of 10 percent per year gives a profit of 99,24 M.

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