DESTIA

COWI

Parainen – Nauvo yhteys

Siltavaihtoehto

Selvitys siltojen ja teiden rakennuskustannuksista

Joulukuu 2008

SISÄLLYSLUETTELO

1 SELVITYKSEN TEKIJÄT

Destia Oy:n infrasuunnitteluyksikkö on yhdessä tanskalaisen yhteistyökumppaninsa COWI A/S:n kanssa päivittänyt Parainen – Nauvo siltayhteyden kustannuksia sekä selvittänyt laivojen törmäysriskin vaikutusta suunnitelmaan ja hankkeen rakentamiskustannuksiin. Työ on tehty Tiehallinnon Turun tiepiirin investointipäällikön Markus Salmen pyynnöstä.

Kustannusarvion päivitys on tehty vuonna 2001 tehtyjen suunnitelmien pohjalta tutkimalla vain Airiston sillan vinoköysisiltavaihtoehtoa. Avattavat sillat ja muut linjavaihtoehdot on jätetty tämän selvityksen ulkopuolelle. Hankkeeseen kuuluu Airiston vinoköysisillan lisäksi myös Maltholmin n. 1200 m pitkä teräspalkkisilta ja n. 10 km pitkä tieyhteys pienempine siltoineen ja liittymineen, joiden kustannusvaikutukset ovat mukana tässä tarkastelussa.

Selvityksen laatimista ovat Destia Oy:ssä tehneet sillansuunnittelun johtava asiantuntija Torsten Lunabba, sillansuunnittelija vanhempi konsultti Eero Meuronen, tiesuunnittelija vanhempi konsultti Pekka Saari ja geotekninen suunnittelija johtava konsultti Matti Manelius. Lisäksi Destia Oy:n erikoisrakentamisen yksikön tarjouslaskija Lauri Seppänen on avustanut yksikköhintojen arvioinneissa.

Airiston vinoköysisillan määrä- ja kustannusarvion päivityksen sekä laivaliikenteen riskiarvion ovat laatineet Destia Oy:n yhteistyökumppanin tanskalaisen insinööritoimisto COWI A/S:n asiantuntijat. Nämä ovat projektipäällikkö Tina Vejrum, suunnittelija Lars Jensen, suurten siltojen suunnitteluyksikön päällikkö Henrik Andersen sekä riskiarvioinnissa Robert Ullner, Oliver Kübler, Kristian Schellenberg ja Ib Jacobsen.

Suunnittelun lähtötietoja ovat antaneet Tiehallinnon Turun tiepiirin investointipäällikkö Markus Salmen lisäksi diplomi-insinöörit Olli Niskanen ja Seppo Aitta Tiehallinnon keskushallinnon siltatekniikka yksiköstä.

Tietoja laivaliikenteestä on antanut Merenkulkulaitoksen väyläpäällikkö Marko Reilimo.

2 YHTEENVETO

Parainen – Nauvo hankkeen kustannusten on arvioitu olevan 140 820 000 miljoonaa euroa. Kustannukset jakaantuvat taulukon 1 mukaisesti.

Kustannuksista n. 112 miljoonaa euroa on siltojen rakentamiskustannuksia, 7,9 miljoonaa teiden ja pienehkön sillan rakentamiskustannuksia, vajaat 6 miljoonaa suunnittelukustannuksia ja reilut 7 miljoonaa euroa rakennuttamiskustannuksia. Pohjatutkimusten osuus on 540 000 €. Tieosuuden telematikkalaitteiden hankintaan ja asennukseen ja hankkeesta johtuviin muihin rakennuttajan kustannuksiin on varattu yhteensä 600 000 €.

Vuonna 2001 tehdyssä Airiston siltasuunnitelmassa laivojen törmäyskuorman riskianalyysi siirrettiin myöhempään ajankohtaan. Nyt tehdyssä selvityksessä on varmuus laivojen törmäystä vastaan todettu kriittiseksi kaikilla veteen rakennettavilla tuilla. Riskitaso on liian suuri jo nykyisillä liikennemäärillä ja riskit kasvavat, mikäli laivojen lukumäärä, alusten koko ja ajonopeudet kasvavat nykyisestä. Varautuminen laivojen törmäystä vastaan edellyttää tukien suojaamista louhetäytöillä tai tukien vahvistamista. Vaihtoehtoisesti voidaan törmäysriskiä vähentää siirtämällä tukirakenteet kuivalle maalle tai ainakin matalampaan veteen. Alustavan arvion mukaan rakennuskustannukset laivojen törmäysriskin huomioon ottamisesta ovat vähintään n. 7 miljoonaa euroa. Tämä nostaa Airiston sillan rakennuskustannukset n. 71 miljoonaan euroon ja sillan hankekustannukset n. 78 miljoonaa euroon, kun mukaan otetaan sillan pohjatutkimus-, suunnittelu- ja rakennuttamiskustannukset.

Maltholmin sillan kohdalla on tänä päivänä toimiva meriväylä. Suunnitellun sillan 20 metrin alikulkukorkeus estää suurempien alusten liikennöinnin tällä väylällä tulevaisuudessa. Sillan rakentamisen myötä väylän merkitys pienentyisi oleellisesti nykyisestä. Väylän kohdalla on kuitenkin tarvetta pienempien alusten liikennöintiin ja tämän takia tulee rakentaa lähinnä väylää olevat sillan tukirakenteet riittävän kestäviksi. Tähän on Maltholmin sillan kustannusarviossa varauduttu. Vastaavaa laivojen törmäyksen riskianalyysiä kuin Airiston sillan kohdalla ei kuitenkaan ole tehty.

Taulukko 1. Kustannuserittely.

Airiston silta	€	€
Rakentamiskustannukset	63 912 000	
Pohjatutkimuskustannukset	155 100	
Suunnittelukustannukset	3 357 500	
Suojaaminen laivaliikenteeltä	7 000 000	
Rakennuttamiskustannukset	3 750 000	78 174 600
Maltholmin silta		
Rakentamiskustannukset	47 750 000	
Pohjatutkimuskustannukset	283 900	
Suunnittelukustannukset	1 857 500	
Rakennuttamiskustannukset	3 000 000	52 891 400
Parainen Nauvo tieyhteys		
Rakentamiskustannukset	7 867 460	
Pohjatutkimuskustannukset	99 000	
Suunnittelukustannukset	630 880	
Rakennuttamiskustannukset	556 660	9 154 000
Tieosan telematiikka	511 000	
Muut hankekustannukset	89 000	600 000
Kaikki yhteensä		140 820 000

Airiston ja Maltholmin siltojen ylläpitokustannukset ovat yhteensä arviolta 1 miljoona euroa vuodessa, mikä on n. 1 % rakentamiskustannuksista. Tiehallinnon vuoden 1998 ohjeessa ”Siltojen hoidon, ylläpidon ja korjausten toimintalinjat” suositusarvo oli silloisten kansainvälisten suositusten mukaan 2 %. Näin korkeisiin arvoihin ei ole Suomessa eikä juuri muuallakaan päädytty. Nykyisissä ohjeissa ei tämän takia ole tarkkoja suositusarvoja annettu, mutta 1 %:n osuutta voidaan joka tapauksessa pitää tässä hankkeessa perusteltuna.

Edellä mainittuihin siltojen ylläpitokustannuksiin sisältyvät siltojen päällysteen kulumisesta aiheutuvat uudelleen päällystämisen kustannukset n. 14000 €/vuosi. Teiden osalta vastaavat kustannukset ovat n. 40 000 €/vuosi. Näitä kuluja ei myöskään oteta huomioon erillisinä, vaan ne katsotaan kuuluvan tien normaaleihin hoitokuluihin.

Sillan telematikan kustannukset ovat 511 000 €. Laitteet on uusittava kerran kymmenessä vuodessa. Koska siltojen telematikka on merkittävä kustannuserä, otetaan tämä erä 51 000 €/vuosi huomioon erillisenä lisänä sillan vuosittaisena hoitokuluna.

3 SILTAKUSTANNUKSET

Airiston sillan rakennuskustannusten on arvioitu olevan ilman suojausta törmäyskuormia vastaan 55,6 miljoonaa euroa. Kun tähän lisätään yhteiskustannukset 25 % ja ennalta arvaamattomat lisäkustannukset 15 %, päädytään 63,9 miljoonaan euroon, mikä tanskalaisen alikonsultin mukaan vastaa hyvin toteutuneita kustannuksia vastaavissa kansainvälisissä hankkeissa.

Alkuperäinen kustannusarvio vuodelta 2001 oli 177,8 miljoonaa markkaa, mikä vastaa 29,9 miljoonaa euroa. Nykyinen kustannusarvio on noin kaksi kertaa suurempi kuin alkuperäinen arvio. Kustannustason noususta n. 50 % selittyy tapahtuneesta yleisestä kustannustason noususta. Yleistä hinnannousua suurempi on ollut sekä rakenne- että betoniteräksen kallistuminen. Alkuperäistä kustannusarviota on lisäksi nostanut arviot ainemenekkien lisääntymisestä ja työn vaikeusasteen kasvamisesta, mikä on nostanut yksikköhintoja erityisesti teräsrakenne-, betoni- ja paalutustöissä. Siltaan tulevat kulkulaitteet ja muut välttämättömät varusteet ja laitteet on lisätty kustannusarvioihin. Lopullisiin siltakustannuksiin on taulukossa 1 lisätty myös pohjatutkimus-, suunnittelu-, rakennuttamiskustannukset sekä suojaaminen laivojen törmäystä vastaan, jotka vuonna 2001 tehdyssä selvityksessä eivät olleet mukana kustannusarviossa.

Maltholmin sillan osalta yksikköhinnat on tarkistettu vastaavalla tavalla kuin Airiston sillassa. Yksikköhinnat ovat tässä sillassa yleensä pienemmät kuin vinoköysisillassa johtuen siitä, että silta on rakenteeltaan tavanomaisempi ja teknisesti helpompi toteuttaa. Toisaalta sillan paalutustyöt ovat Maltholmin sillassa vähintään yhtä vaativat kuin Airiston sillassa. Maltholmin sillan rakentamiskustannukset ovat nyt tehdyn arvion mukaan 47,75 miljoonaa euroa, mikä on myös noin kaksi kertaa suurempi kuin vuonna 2001 tehty arvio. Hintaero selittyy kustannustason nousulla ja eräiden suorite-erien puuttumisesta alkuperäisessä arviossa. Uudessa hinta-arviossa ovat mukana myös ennalta arvaamattomat kustannukset ja lisätyöt, jotka ovat 10 % rakennuskustannusten ja työmaan yhteiskustannusten summasta.

4 MÄÄRÄLUETTELOT

Airiston sillan kohdalla on tanskalainen alikonsultti saanut merkittäviä eroja useissa suoritemäärissä (katso kohta 5.9). Kaivu- ja perustustöiden osalta ero saattaa selittyä yksityiskohtaisten pohjatietojen puuttumisesta, minkä takia tanskalainen konsultti on olettanut olosuhteet vaikeammaksi kuin alkuperäinen suomalainen suunnittelija. Tämän lisäksi on Cowi A/S katsonut, että betonirakenteiden raudoitussuhteen tulee useissa rakenneosissa olla suurempi. Määräluetteloon on myös lisätty uusia suoritteita, kuten välttämättömänä pidetty esijännitys pylonien poikkipalkeissa sekä varmistus nousua vastaan takaköysien välituilla. Alkuperäisessä selvityksessä sillan kulkuyhteydet on kuvattu selostuksessa mutta ne eivät ole mukana määräluettelossa. Kulkuyhteydet on nyt lisätty tämän selvityksen kustannusarvioihin.

Maltholmin sillan kohdalla on pääosin pitäydytty aikaisemmissa määräluetteloissa. Sillan kansirakenne on nyt tehdyssä kustannusarviossa tarkasteltu avoimena poikkileikkauksena alkuperäisen kotelorakenteen sijasta. Tämä on mahdollista, mikäli alapaarteet vahvistetaan betonilaatalla pääukkojen tukialueella. Näin menetellen voidaan kustannuksia alentaa vaikka kannen alapuolelle joudutaan lisäämään tarkastus- ja huoltotyötä helpottava hoitosilta.

5 AIRISTON SILTA

5.1 Palkit

Airiston sillasta on alkuperäisessä suunnitelmassa esitetty ainoastaan kaaviomuotoiset siltapalkit, pyloni ja välituet. Tanskalainen yhteistyökumppani on pitänyt välttämättömänä tehdä alustava suunnitelma kaikille rakenteille nojautuen kokemukseensa vastaavista projekteista. Määräluettelo on tämän takia merkittävästi muuttunut.

Vinoköysisillan palkin painoksi on arvioitu 13 tonnia/m ja ramppisillan 11 tonnia/m. Näihin arvoihin lisätään pintarakenteet, reunakorokkeet ja muut varusteet ja laitteet.

5.2 Pylonit

Vinoköysien ankkurit on sijoitettu koteloon. Alkuperäinen siltapiirustus osoittaa, että pylonin varsi on alhaalla vedenpinnan yläpuolella kotelomainen mutta leikkauksesta D-D (tasosta +14 ylöspäin) massiivinen. Ottaen huomioon rakenteen mitat on epätaloudellista ja tarpeetonta valita pyloniin yläosaan massiivinen poikkileikkaus. Kotelorakenteella on myös se etu, että siihen voidaan sijoittaa suojattu kulkuyhteys vinoköysien ankkurikappaleille.

5.3 Välituet

Alkuperäisessä suunnitelmassa ei juuri ole tietoa välitukipilareiden poikkileikkauksesta. Tämän takia on tässä selvityksessä pilarien poikkileikkaus oletettu samantapaiseksi kuin pylonien, eli varsi on kotelorakenne 0,4 m:n seinämäpaksuudella. Välituki 4, joka on vedessä, on oletettu massiiviseksi tasoon +2 m saakka. Pilari kestää tällä tavalla paremmin jääkuormia ja alusten törmäyskuormia.

5.4 Köysijärjestelyt ja poikkipalkit

Vinoköysiväliksi on sekä pää- että reunajänteissä oletettu 14 m. Etäisyys pylonista ensimmäisiin köysiin on 17 m. (Lähes sama kuin alkuperäisessä). Poikkipalkkiväli on 14m/4=3,5 m vinoköysiosassa ja 4 m reunajänteissä.

5.5 Laakerointi

Pääkannattimella on oletettu olevan kaksi tukipistettä jokaisen maatuen, pilarin ja pylonin kohdalla. Laakereiden lukumäärä on 16. Laakerityypiksi on oletettu joko kumipesälaakeri tai kalottilaakeri, jonka mitat ovat pienemmät. Pääkannatin on pituussuuntaan kiinnitetty tuen T5 kohdalla. Molemmat maatuet varustetaan liikuntasaumalaitteilla.

5.6 Perustukset

Alustavien piirustusten mukaan kallion pinta on tasossa -18 m ja -31 m pylonien T5 ja T6 kohdalla. Tässä tarkastelussa näiden tasojen on oletettu olevan kiinteää kalliota, mihin tukirakenteet voidaan perustaa. Perustamistasot on esitetty taulukossa 2. Taulukossa 2 annettujen arvojen mukaan on laskettu tarvittava kaivu- ja louhintatyö. Lopullisen suunnittelun yhteydessä on tukien pohjatiedot hankittava ja siinä yhteydessä perustamistasot varmistettava.

Taulukko 2. Perustamistasot.

Tuki	Perustamissyvyys
T2	7m
T3	4m
T4	5m
T5	6m
T6	Paalutettu
T7	8m

5.7 Airiston sillan rakentamistapa

Oletettavasti silta rakennetaan tasapainotetulla ulokemenetelmällä ilman tilapäisiä tukia reunajänteissä. Tällöin on otettava huomioon, että rakentamisjärjestyksellä ja betonin lujittumisen ajoituksella on merkitystä oman painon normaalivoimien jakautumiselle liittorakenteessa. Tässä tarkastelussa on oletettu betonilaatan olevan täysin liittorakenteinen siinä vaiheessa, kun köydet jännitetään.

5.8 Airiston sillan yksikköhinnat

Taulukko 3. Airiston sillan tärkeimmät yksikkökustannukset.

Suorite	Yksikköhinta
Betonityöt	
Paikalla valettu tai esivalmistettu betonirakenne, valutyö mukaan luettuna, standardirakenne	200EUR/m^3
Paikalla valettu tai esivalmistettu betonirakenne, valutyö mukaan luettuna, korkea raudoitussuhde (kansilaatta)	300EUR/m^3
Paikalla valettu betoni valutyö mukaan luettuna, vaikea muoto (välituet)	300EUR/m^3
Paikalla valettu betoni valutyö mukaan luettuna, vaikea muoto ja suuret rakenteet (pylonit)	410EUR/m^3
Paikalla valettu betoni vedenalaisena valuna	420EUR/m^3
Muotit ja telineet stadardityönä	85-90EUR/m^2
Muotit ja telineet, vaikea rakenne, kiipeävä muotti	95EUR/m^2
Raudoitus, standardi	2.00EUR/kg
Raudoitus, vaikea muoto (välituet ja pylonit)	2.30EUR/kg
Rakenneteräs	
Laatu S355 J2+N, sisältäen korroosiosuojauksen ja asennuksen kannen tasossa (siltapalkit)	4.50EUR/kg
Laatu S355 J2+N, sisältäen korroosiosuojauksen ja asennuksen korkealla (pylonien ankkurikotelot)	5.00EUR/kg
Köydet ja esijännittäminen	

Suorite	Yksikköhinta
Punos, sisältää vain punoksen painon.	10.40EUR/kg
Sekalaista	
Paalut, betonitäytteiset teräsputkipaalut Ø1200, lyötynä	1500EUR/m
Kaide, Eurooppalainen Standardi tyyppi H2	350EUR/m
Pintarakenteet, kaksinkertainen huopa	45EUR/m^2
Päällyste, kokonaispaksuus 11mm	25EUR/m^2

5.9 Suoritemäärien vertailu

Taulukko 4. Suoritemäärien vertailu.

Tunnus	Kuvaus	Alkuperäinen määrä	Päivitetty määrä	Huomautukset
7111	Kaivu ilman tuentaa	4,000m^3	5,000m^3	Ero johtunee pohjatietojen puuttumisesta.
7141	Perustukset, telineet ja muotit	1,110m^2	4,100m^2	Muotin pinta-ala liittyy suoraan arvioituihin betonimääriin, katso kohta 7144.
7142	Perustukset, raudoitus	262,000kg	470,000kg	Teräsmäärä liittyy suoraan arvioituihin betonimääriin, katso kohta 7144.
7144	Perustukset, betonityöt	570m^3	2,700m^3	Ero johtunee pohjatietojen puuttumisesta. Nyt tehtyjä arvioita pidetään realistisina.
7152	Maatuet, raudoitus	32,000kg	38,400kg	Tanskalaisten kokemusten mukaan raudoitussuhteen tulee olla jonkin verran suurempi.
7161	Välituet, telineet ja muotit	16,450m^2	40,000m^2	Arviointiperusteet ovat muuttuneet. Päivitetyt arviot ovat yhteensopivat valittujen yksikköhintojen kanssa.
7162	Välituet, raudoitus	515,000kg	1,188,000kg	Tanskalaisten kokemuksen mukaan raudoitussuhteen tulee olla huomattavasti suurempi kuin alkuperäisessä kustannusarviossa.
7163	Välituet, esijännitys	-	9,200kg	Uusi kustannuserä: pylonin poikkipalkki on

Tun-nus	Kuvaus	Alkuperäi-nen määrä	Päivitetty määrä	Huomautukset
				esijännitetty.
7173	Päällysrakenne, esijännitys ja köysirakenteet	-	20,000kg	Uusi kustannuserä: kansi on ankkuroitu pilareihin T4 and T7.
7176	Yläpuoliset rakenteet, rakenneteräs, ankkurikotelot	200,000kg	255,000kg	Tanskalaisten kokemuksen mukaan teräsmäärän tulee olla suurempi kuin alkuperäisessä kustannusarviossa
7194	Muut varusteet ja laitteet, huoltovaunu	-	1 kpl	Uusi varuste, joka on mainittu mutta ei sisällytetty alkuperäiseen kustannusarvioon.
7194	Muut varusteet ja laitteet, kulkuyhteydet (portaat, luukut)	-	1 kpl	Uudet varusteet, joita on mainittu mutta ei sisällytetty alkuperäiseen kustannusarvioon.
7194	Muut varusteet ja laitteet, laiva- ja lentoliikennevalot	-	1 kpl	Uudet varusteet, joita ei ole sisällytetty alkuperäiseen kustannusarvioon.
7196	Monitorointilaitteet: peruslaitteet sisältäen sääaseman, kannen lämpötilan, valittujen köysien värähtely, kamerat	-	1 kpl	Uudet varusteet, joita ei sisällytetty alkuperäiseen kustannusarvion.
-	Urakoitsijan tilapäisten rakenteiden suunnitelmat ja asennuksen seuranta	-	1 kpl	Uusi kustannuserä, joka ei sisältynyt alkuperäiseen kustannusarvioon.
-	Sekalaiset /Satunnaiset erät	-	1 kpl	Uusi kustannuserä, joka ei sisältynyt alkuperäiseen kustannusarvioon.
-	Lopullinen rakennesuunnittelu	-	1 kpl	Uusi kustannuserä, joka ei sisältynyt alkuperäiseen kustannusarvioon.
-	Rakennuttaminen	-	1 kpl	Uusi kustannuserä, joka ei sisältynyt alkuperäiseen kustannusarvioon.

6 LAIVOJEN TÖRMÄYS

Alkuperäisessä suunnitelmaselostuksessa on laivojen törmäysriski mainittu mutta jätetty yksityiskohtaisempien tietojen puuttuessa ottamatta huomioon. Koska törmäysriski näin isossa sillassa vaikuttaa merkittävästi koko sillan suunnitteluun ja sen kustannuksiin, riskit on tässä tapauksessa selvitetty ainakin yleissuunnittelun vaatimustason mukaisesti.

Tiehallinnon ohjeen "Siltojen kuormat" kohdan 3.8.3 mukaan aluksen törmäyskuormat olisivat Airiston sillan kohdalla 65 MN. Sisävesiväylillä, joihin Matholmin sillan voidaan katsoa sillan valmistumisen jälkeen kuuluvan, törmäyskuorma olisi pienempi, mutta kuorman suuruus tulee selvittää tulevan laivaliikenteen mukaan.

Mikäli Airiston ja Maltholmin sillat rakennetaan 1.4.2010 jälkeen, Suomessa on noudatettava Eurokoodeja. Eurokoodit antavat paremman pohjan laivojen törmäykseen liittyvien riskien arviointiin, vaikkakin kansallisista sovellusohjeista Suomessa ei ole vielä päätetty.

Maltholmin siltapaikka muuttunee sillan rakentamisen jälkeen sisäveteen verrattavaksi vähäiseksi väyläksi, missä aluskoko on enintään 3000 DWT. Törmäyskuorman suuruuden suuntaa antavat arvot olisivat Eurokoodin 1991-7 liitteen C mukaan 8 MN väylän suunnassa ja 4 MN kohtisuoraan väylää vastaan. Näille kuormille väylää lähinnä olevat tuet voidaan mitoittaa. Mikäli väylällä liikkuisi veto- tai työntöproomuja, törmäysriskit kasvaisivat merkittävästi eikä näihin riskeihin ole nyt päivitetyssä kustannusarviossa varauduttu.

Eurokoodin 1991-7 liite C antaa Airiston sillan törmäyskuorman ohjearvoksi 80 MN väylän suunnassa ja 40 MN kohtisuoraan väylää vastaan. Aluksen koko tällä ohjearvolla on 10 000 tonnia, mikä on sama kuin nykyinen suurin alus tällä väylällä. Eurokoodin hengen mukaista on kuitenkin näin merkittävässä sillassa tehdä riskiarviointi. Tällä arvioinnilla voidaan ottaa paremmin huomioon eri tukien riskitaso ja etäisyys väylän reunasta.

Tanskalainen COWI A/S:n asiantuntija on valinnut hyväksyttäväksi riskitasoksi Amerikkalaisten Aashto määräysten mukaan 0,0001/vuosi, mikä on 1 törmäys 10 000 vuodessa. Eurokoodien 1991-7 liitteen B taulukon B.2 mukaan tämä riskitaso vastaa keskitasoa. Koska yhdenkin vedessä olevan tuen sortuminen johtaa koko sillan romahtamiseen, hyväksyttävä riskitaso voisi olla jopa 10 kertaa pienempi ja mitoitus tämän takia ankarampi. Tanskalainen alikonsultti on kuitenkin tehnyt mitoituksen amerikkalaisten määräysten mukaan, koska sovittuja sääntöjä Eurokoodien soveltamisesta ei vielä ole ja koska Eurokoodien liitteessä A on toisaalta annettu hyväksyttäväksi tasoksi sama luku 0,0001, joka on myös Aashto normeissa. Mikäli mitoitus tehtäisiin Eurokoodien ankarimman mitoitussäännön mukaan, suojaamista törmäystä vastaan tulisi parantaa, mikä lisäisi rakentamiskustannuksia.

Tanskalainen konsultti on arvioinut eri tukien kestävyydet vaakakuormia vastaan taulukon 5 mukaisiksi.

Taulukko 5. Tukien kestävyys.

	Tuki T4	Pyloni T5	Pyloni T6
Tuen vaakasuora kapasiteetti (MN)	8.6	75.1	33.0

Koska pylonituella T5 on riittävä kapasiteetti laivan törmäystä vastaan, todennäköisyys sillan vaurioitumiseen laivan törmäyksestä muodostuu lähinnä osumista tukiin T4 ja T6. Mikäli alusten määrä on 1500-3000 vuodessa, todennäköisyys sillan sortumiselle on 1,2-2,5 kertaa yli sallitun arvon jo alusten nopeudella 9 solmua. Mikäli liikennemäärä on nykytasolla ja laivojen nopeudet nykyiset, sallitun todennäköisyyden ylitys on moninkertainen ja riskitaso kestämätön.

Koska vakava laivaonnettomuus todennäköisesti aiheuttaisi suurten aineellisten ja yhteiskunnallisten menetysten lisäksi useiden ihmisten hengenmenetyksen, vedessä olevien tukien vaadittavaksi kestävyydeksi suositellaan taulukon 6 mukaisia arvoja.

Taulukko 6. Vaadittu tukien kestävyys.

	Tuki T4	Pyloni T5	Pyloni T6
Tuen vaakasuora kapasiteetti (MN)	25	75	100

Näihin arvoihin päästään, mikäli tuet T4 ja T6 suojataan louhetäytöllä ja tuki T5 tehdään riittävän vahvaksi. Mikäli louhetäyttöä ei ympäristö- tai kustannussyistä voida hyväksyä, tukien T4 ja T6 vahvistaminen rakentamalla ne kallioon upotettujen järeiden kasuunien varaan on varteen otettava vaihtoehto. Lisäkustannusten arvioidaan olevan tässäkin tapauksessa vähintään n. 7 miljoonaa euroa.

7 LIITTEET

Liite 1 Evaluation of Airisto Stay Cable Bridge, Review of Quantities and Cost Estimate, evaluation by COWI A/S September 2008

Liite 2 Evaluation of Airisto Stay Cable Bridge, Ship Collision Risk Assessment and Estimate of Protection Structures, evaluation by COWI A/S September 2008

Liite 3 Malthomin silta, alustava piirustus, Maltholmen_silta.pdf

Liite 4 Malthomin silta, kustannusarvio, Maltholmen Kust.arv.PDF

Liite 5 Parainen_Nauvo_Tiekustannukset.PDF

8 LÄHDEKIRJALLISUUS

/1/ Siltojen kuormat TIEL 2172072-99
/2/ Eurocode 1991-1-7: Rakenteiden kuormat. Yleiset kuormat, Onnettomuuskuormat
/3/ Siltojen hoidon, ylläpidon ja korjausten toimintalinjat 1998, TIEH 2230051
/4/ Siltojen ylläpito, toimintalinjat 2005 , TIEH 1000090-05
/5/ AASHTO LRFD Bridge Design Specifications
American Association of State Highway and Transport Officials

Finnish Road Administration, Turku Road Region

Evaluation of Airisto Stay Cable Bridge

Review of Quantities and Cost Estimate

September 2008

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Evaluation of Airisto Stay Cable Bridge

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Table of Contents

1 Introduction

The scope of the present study is to assess and update the cost estimate of the Airisto Stay Cable Bridge (440m main span) at the planned fixed link between Parainen and Nauvo in South Western Finland, in co-operation with the Turku Road Region of the Finnish Road Administration (Finnra).

The study comprises the following elements:

- Evaluation of the bill of quantities presented in the existing design;
- Evaluation of the cost estimate based on the updated bill of quantities;
- Evaluation of the feasibility of the bridge design.

The background information forming the basis of the study is listed in Section 6 References.

2 Summary and Conclusions

The construction cost of the Airisto Stay Cable Bridge is estimated to 55.6 million Euros including 25% overhead to establish and run the construction site. In addition it is proposed to include 15% contingency to cover miscellaneous items and fluctuations leading to a total construction cost of 63.9 million Euros. Finally, the cost of carrying out detailed design, preparing tender documents and site supervision during the construction period shall be added. Hence the total cost of designing and constructing the Airisto Stay Cable Bridge is estimated to 70.9 million Euros. Based on our experience this estimate is deemed realistic as compared to similar international projects.

The original cost estimate from 2001 for the bridge excluding road works was 177.8 million Fmk, equivalent to 29.9 million Euros. Thus the updated construction cost estimate is about twice the original value. Apart from general inflation, a major contribution to the increase in cost is the significant increase in steel prices over the last approximately 5 years which has an impact on the cost of reinforcement as well.

In addition to the difference in unit cost adopted in the original study and in the present cost estimate, a significant difference in the estimated quantity is noted for a number of elements. In case of excavation and foundation works the difference may be explained by the lack of detailed geotechnical information at the bridge site. Consequently, different assumptions will inevitably have been adopted in the original and in the present study. In addition, the reinforcement ratio shall be higher for a number of elements according to our experience.

Finally, a number of new items have been included in the bill of quantities: It is deemed necessary to include pre-stressing of the pylon cross beams and a tie-down arrangement at the anchor piers. Furthermore, access facilities and a basic monitoring system have been briefly described in the original study, but were not included in the bill of quantities. This is now included in the present study. Finally, the cost of detailed design, tender documents and site supervision have been assessed and included.

3 Assumptions

This section presents the assumptions that have been necessary in order to carry out the present assessment of quantities and cost estimate for the Airisto Stay Cable Bridge.

3.1 General Arrangement

3.1.1 General Arrangement

The review is based on the general arrangement as shown in Figure 2 of Reference /1/. The General Arrangement Drawing is included in Appendix 1 for ease of reference.

3.1.2 Dimensions and Cross Sections

Only the generic layout of bridge girder, pylon and piers are given; Figure 3 in Reference /1/ refers (included in Appendix 1 for ease of reference). Consequently, it has been necessary to carry out a basic design of all major structural elements based on experience from similar projects. The result of this basic design is reflected in the updated quantities.

Girder
The weight of the composite girder in the cable supported portion of the bridge is estimated to 13tons/m while the weight of the composite girder in the approach spans is estimated to 11tons/m. The weight of surfacing, parapets, ancillary works and access facilities shall be added to the above values for the completed structure.

Pylons
The stay cables are anchored in a steel anchor box. The original design drawing appears to indicate that the shaft above water is hollow whereas the legs from Section D-D at level +14m to the top are solid (Figure 3 in Reference /1/ refers, see Appendix 1). However, due to the overall dimensions of the cross section it is considered both uneconomical and unnecessary to adopt a solid section in the upper part of the pylon. Furthermore, by adopting a hollow section access to the pylon top and stay anchorages can conveniently be arranged inside the structure in a protected environment.

Consequently, in the present study the pylon legs are assumed to be hollow structures with a wall thickness of 0.8m in the shaft up to level +14m, where the wall thickness is reduced to 0.5m in the remaining part of the pylon structure. The shaft is solid from foundation level to level +2.0m to transfer forces from ice and to provide some robustness against ship impact (see also comment regarding the pylon design in Section 5.2.1 Ship Impact). The cross beam is pre-stressed to balance the deviation force from the inclined legs.

Piers
The original design does not provide information on the cross section of the piers. For the purpose of the present study the overall shape of the cross section is assumed to be similar to the pylons, hollow and with a wall thickness of 0.4m. Pier T4, which is located on water, is assumed to have a solid cross section from foundation level to level +2.0m to transfer forces from ice.

3.1.3 Stay Cable Spacing

The typical stay cable spacing is taken as 14m in both main span and side spans. The distance from the pylon to the first set of stay cables is assumed to be 17m.

3.1.4 Cross Girder Spacing

The cross girder spacing is taken as 14m/4 = 3.5m in the cable supported portion of the bridge and 4.0m in the approach spans.

3.1.5 Supports and Expansion Joints

The girder is assumed to have two supports on each abutment, pier and pylon, respectively, leading to a total number of bearings of 16. The bearing type is assumed to be either pot bearings or spherical bearings,- the latter offering slightly smaller dimensions. The girder is assumed to be longitudinally fixed on pylon T5 with expansions joints at each abutment.

3.1.6 Foundations

According to Reference /1/ the surface of the rock is located at level -18m and -31m at the position of the two pylons, T5 and T6. For the purpose of the present review the quoted levels are assumed to represent sound rock and are consequently taken as the foundation levels. The assumed foundation depths (below the surface) are listed in Table 1. These depths determine the required volume of excavation. However, it should be noted that no detailed geotechnical information has been available in the present study and consequently the assumptions are subject to confirmation at a later stage; see also Section 5.2.2 Geotechnical Investigations.

Location	**Foundation Depth**
T2	7m
T3	4m
T4	5m
T5	6m
T6	N/A
T7	8m

Table 1. Assumed Foundation Depth.

3.2 Materials

3.2.1 Stay Cables and Pre-stressing

The stay cable system is assumed to be of the multi strand type consisting of 7-wire 15.7mm Dia. strands with a tensile strength of 1860MPa. The strand bundle is protected by a HDPE stay pipe.

The same type of strands is used for pre-stressing of the pylon cross beams and tie-down arrangement at piers T4 and T7.

3.2.2 Structural Steel

The steel for the composite girder and anchor boxes is assumed to be grade S355 J2+N or equivalent. No information on steel grade is given in the original design.

3.2.3 Concrete

Concrete of different grade is used varying from K30/K35 in foundations and abutments to K40/K50 in the superstructure and in piers and pylons in agreement with the original design.

3.2.4 Reinforcement

The reinforcement is assumed to be grade A500HW as in the original study. The amount of reinforcement varies from 100kg/m^3 to 200kg/m^3 depending on location and type of structural element.

3.2.5 Surfacing

The total thickness of the surfacing is assumed to be 110mm.

3.3 Loading

3.3.1 Traffic Load

The bridge is assumed to carry three lanes of traffic. The uniform load is $3kN/m^2$ with a load factor of 1.8 in ULS in accordance with Finnish Standard.

3.3.2 Wind Loading

The wind climate at the bridge site is described in Reference /2/ (only available in Finnish language) and /3/. The 10-minute mean wind speed at 10m's height is given as 33m/s for a return period of 100 years.

For the purpose of the present investigation the drag coefficient of the composite section is taken as $C_d = 1.4$.

3.3.3 Current

No specific information on current at the bridge site is currently available.

3.3.4 Ship Impact

No site specific information on forces from ship impact is currently available, also refer to comments in Section 5.2.1.

3.4 Construction

3.4.1 Construction of the Cable Stayed Bridge

It is assumed that the main bridge will be constructed by balanced cantilevering without temporary supports in the side spans. It is noted that the construction sequence, and notably the timing of when the concrete slab is made continuous, has an influence on the distribution of normal force originating from dead load in the composite cross section. For the purpose of the present study the concrete slab is assumed to be fully composite with the steel boxes at the time of stressing the stay cables.

3.4.2 Casting under Water

It is assumed that the foundation slabs for pier T4 and the pylons T5 and T6 are cast under water whereas the corresponding pier shafts up to level +0.5m are prefabricated as hollow structures, floated into position and then filled with concrete. All the remaining foundations are cast in the dry.

4 Bill of Quantities

The updated bill of quantities including an updated cost estimate is included in Appendix 2.

The construction cost of the Airisto Stay Cable Bridge is estimated to 55.6 million Euros including 25% overhead to establish and run the construction site. In addition it is proposed to include 15% contingency to cover miscellaneous items and fluctuations leading to a total construction cost of 63.9 million Euros. Finally, the cost of carrying out detailed design, preparing tender documents and site supervision during the construction period shall be added. Hence the total cost of designing and constructing the Airisto Stay Cable Bridge is estimated to 70.9 million Euros. Based on our experience this estimate is deemed realistic as compared to similar international projects.

The original cost estimate from 2001 for the bridge excluding road works was 177.8 million Fmk, equivalent to 29.9 million Euros. The original cost estimate is included in Reference /1/. Thus the updated construction cost estimate is about twice the original value. Apart from general inflation, a major contribution to the increase in cost is the significant increase in steel prices over the last approximately 5 years which has an impact on the cost of reinforcement as well.

The table below lists the unit prices for the major elements that have been adopted in the present cost estimate.

Description	**Unit price**
Concrete Works	
In-situ or prefabricated concrete, including casting, standard	200EUR/m^3
In-situ or prefabricated concrete, including casting, high reinforcement ratio (deck slab)	300EUR/m^3
In-situ concrete, including casting, complex geometry (piers)	300EUR/m^3
In-situ concrete, including casting, complex geometry and	410EUR/m^3

Description	Unit price
tall structures (pylons)	
In-situ concrete, including casting under water	420EUR/m^3
Scaffolding and moulds, standard	85-90EUR/m^2
Scaffolding and moulds, complex geometry, climb forming	95EUR/m^2
Reinforcement, standard	2.00EUR/kg
Reinforcement, complex geometry (piers and pylons)	2.30EUR/kg
Structural Steel	
Grade S355 J2+N, including corrosion protection and installation at deck level (bridge girders)	4.50EUR/kg
Grade S355 J2+N, including corrosion protection and installation at height (anchor boxes)	5.00EUR/kg
Stay Cables and Pre-stressing	
Strand, including corrosion protection and installation. The quantity listed in the Bill of Quantities is based on the weight of the bare steel cross section.	10.40EUR/kg
Miscellaneous	
Piles, concrete filled steel piles Ø1200, installed	1,500EUR/m
Parapet, European Standard type H2	350EUR/m
Surfacing, double membrane	45EUR/m^2
Surfacing, total thickness 110mm	25EUR/m^2

Table 2. Unit Prices for Main Elements.

In addition to the difference in unit cost adopted in the original study and in the present cost estimate, a significant difference in the estimated quantity is noted for the following elements:

Code	Description	Original Quantity	Updated Quantity	Comments
7111	Excavation without strutting	4,000m^3	5,000m^3	The difference is probably linked to the lack of detailed geo-technical information; see also Section 5.2.2 Geotechnical Investiga-tions.
7141	Foundations, scaffolding and moulds	1,110m^2	4,100m^2	The amount of form-work is directly linked to the estimated vol-ume of concrete, see comment below.
7142	Foundations, reinforcement	262,000kg	470,000kg	The amount of rein-forcement is directly linked to the estimated volume of concrete, see comment below.
7144	Foundations, concrete works	570m^3	2,700m^3	The difference may be explained by the gen-eral uncertainty regard-ing foundations. The current estimate is con-sidered realistic. No information on the as-sumptions in the origi-nal design is available.
7152	Abutments, reinforcement	32,000kg	38,400kg	According to our ex-perience the reinforce-ment ratio for abut-ments should be somewhat higher than assumed in the original study.
7161	Intermediate supports, scaf-folding and moulds	16,450m^2	40,000m^2	Different approaches to assessing the amount of formwork appears to have been adopted. The current estimate in combination with the

Code	Description	Original Quantity	Updated Quantity	Comments
				adopted unit cost is considered realistic.
7162	Intermediate supports, reinforcement	515,000kg	1,188,000kg	According to our experience the reinforcement ratio for piers and pylons should be considerably higher than assumed in the original study.
7163	Intermediate supports, prestressing	-	9,200kg	New item: Prestressing of pylon cross beams required.
7173	Superstructure, pre-stressing and cable structures	-	20,000kg	New item: Tie-down arrangement at the anchor piers (T4 and T7) required.
7176	Superstructure, structural steel, anchor boxes	200,000kg	255,000kg	According to our experience from similar projects the amount of steel in the anchor boxes needs to be increased as compared to the original study.
7194	Other equipment and accessories, access gantry	-	1 no	New item not included in original estimate.
7194	Other equipment and accessories, access facilities (ladders, hatches)	-	1 no	New item not included in original estimate.
7194	Other equipment and accessories, navigation and aviation lights	-	1 no	New item not included in original estimate.
7196	Monitoring system: Basic system consisting of Weather station, temperature of surfacing, cable vibrations for selected stay cables, cameras	-	1 no	New item not included in original estimate.

Code	Description	Original Quantity	Updated Quantity	Comments
-	Contractor's design of tempo-rary works	-	1 no	New item not included in original estimate.
-	Miscellaneous items / contin-gency	-	1 no	New item not included in original estimate.
-	Detailed design and tender documents	-	1 no	New item not included in original estimate.
-	Construction supervision	-	1 no	New item not included in original estimate.

Table 3. Comparison of Quantities.

5 Comments to the Design

5.1 Comments to the Current Design

5.1.1 Corrosion Protection of Steel Boxes - Internal Surfaces

It is suggested to consider installing a dehumidification system inside the steel boxes of the composite bridge girder. This will reduce the requirements to coating thickness from a full paint system to primer only. Since the majority of the total steel surface is located inside the girder, the reduction of coating thickness on these surfaces will reduce the initial cost considerably. Furthermore, the cost of future maintenance is significantly reduced since re-painting of internal surfaces will not be required. Due to Health, Safety and Environmental requirements blasting and painting inside a confined space like a bridge girder becomes costly whereas the cost of operating a dehumidification system is modest in comparison according to our experience.

5.1.2 Corrosion Protection of Anchor Boxes

It is suggested to consider installing a dehumidification system in the steel anchor boxes in the pylons. Similar to the internal surfaces in the steel boxes, the anchor boxes represent a confined space and some areas will become practically inaccessible for blasting and re-painting after installation of the stay cables. Sealing the anchor boxes to create an airtight compartment will be relatively simple. Consequently, the durability may be increased and maintenance cost reduced by providing dehumidification inside the anchor boxes.

5.1.3 Cross Girders in the Approach Spans

The distance between the webs in the girder is 7m in the current design which means that the thickness of the concrete slab has to be increased unless an intermediate support of the slab is provided. Consequently, it is suggested to invert the shown truss diaphragm/cross girder to provide a support at the centre of the concrete slab.

5.1.4 Cross Girders in Main Bridge

The original design indicates full plate cross girders between the two steel boxes. This design has been adhered to in the present study. However, the weight of the central part of the cross girders could be reduced if changed from a full plate to a truss similar to the layout in the approach spans.

5.2 Feasibility and Future Investigations

The concept for the Airisto Stay Cable Bridge as presented in the original design, with modifications and updates of quantities as presented above, is generally considered feasible. However, a number of fundamental investigations are still outstanding and should be clarified as part of the detailed design if the project is taken to the next phase. The most important of these investigations, which will potentially have an impact on the final quantities and therefore the cost, are briefly described in the following.

5.2.1 Ship Impact

The magnitude and risk of ship impact has not been assessed in any of the earlier studies made available to us. Since both pylons and pier T4 are located on a water depth able to accommodate vessels of a considerable size, the risk of ship collision needs to be assessed and possible mitigation measures investigated. Mitigation may consist of increasing the main span, strengthening of pylons, pier and foundations or providing separate ship collision protection. The scope of the present study is to evaluate the existing design. However, a Ship Collision Risk Assessment is currently under preparation and will be reported under separate cover.

5.2.2 Geotechnical Investigations

If it is decided to take the bridge alternative to the next phase it is recommended to carry out more detailed geotechnical investigations at the bridge site in order to provide a more reliable identification of foundation levels and soil/rock properties.

5.2.3 Aerodynamic Response

Due to the layout of the composite girder being open at the bottom between the two steel boxes in combination with the location of the bridge where low turbulence wind flow must be expected, the cable stayed bridge is considered potentially prone to vortex shedding excitation. It is recommended to carry out a general assessment of the aerodynamic behaviour of the bridge to identify any adverse aerodynamic response and provide an outline of mitigation measures as necessary.

6 References

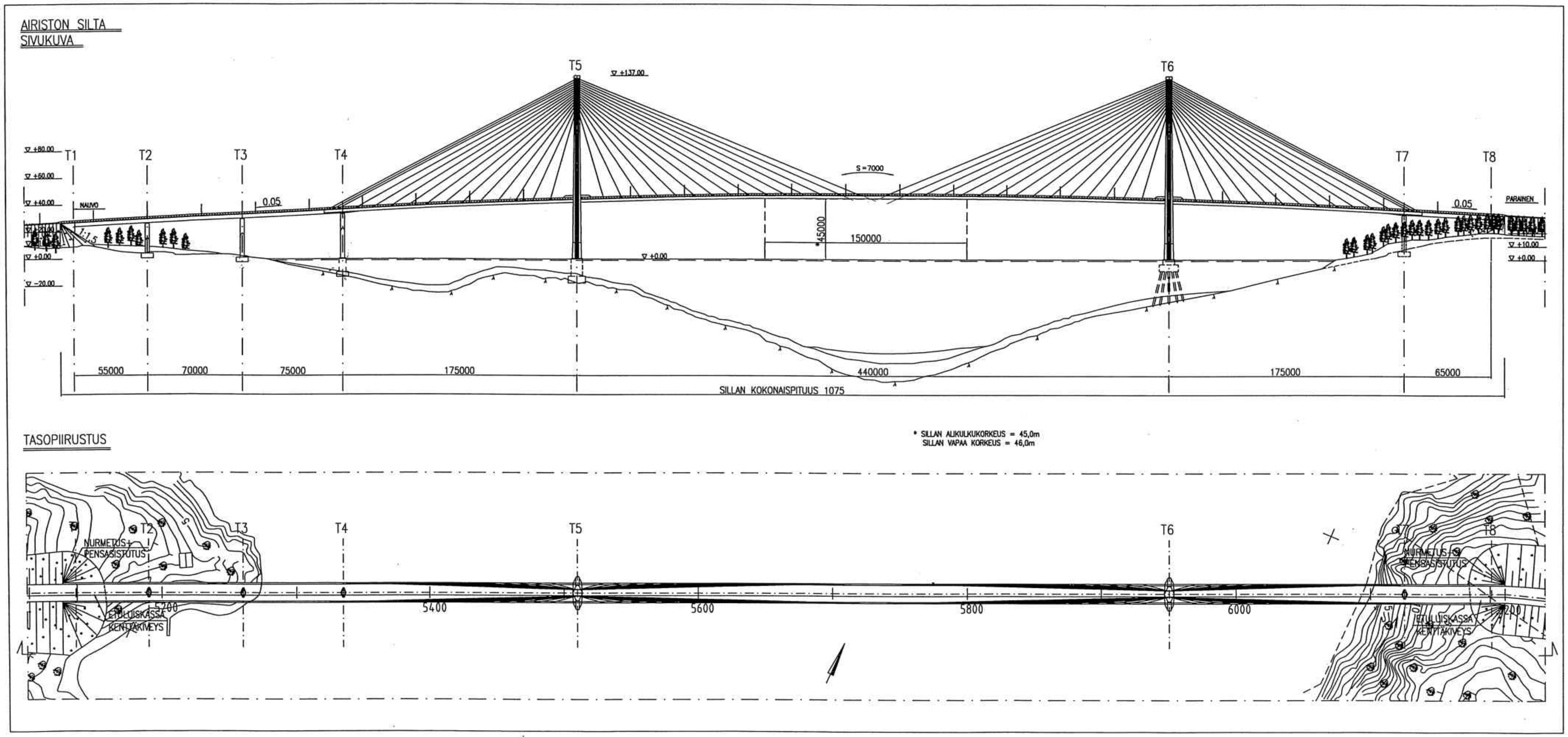
/1/ Parainen - Nauvo kiinteä yhteys
Tiehallinto
2001
(including English translation)

/2/ Airiston sillan tuuliolosuhteet
Tieliikelaitos
2001

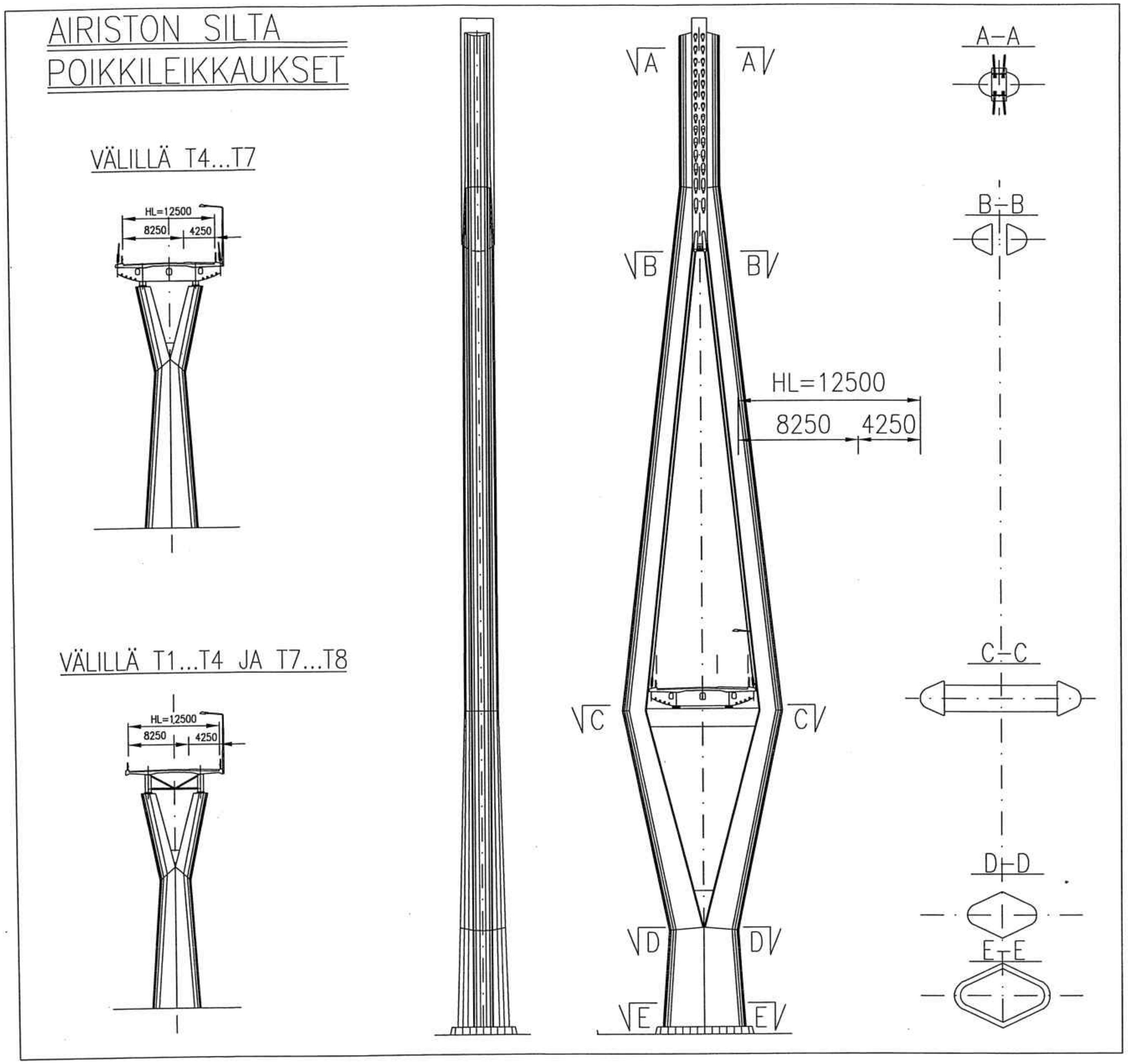
/3/ Pargas - Nagu fast förbindelse
Miljökonsekvensbeskrivning
Vägförvaltningen
2002

Appendix 1 - Original Design Drawings

Appendix 2 - Bill of Quantities



Kuva 2 Vinoköysisilta



Kuva 3 Vinoköysisillan poikkileikkaukset

Code	Description	Quantity	Unit	Unit cost Euro	Cost Euro	Total Euro
7100	BRIDGE CONSTRUCTION					
7110	EXCAVATION AND QUARRYING OF FOUNDATION PITS					
7111	Excavation without strutting	5 000	m^3	10.00	50 000	
7114	Quarrying + (cleaning of rock surface)					
	-surface quarrying H<1.0m	275	m^2	41.00	11 275	
	-quarrying H>1.0m	550	m^2	186.00	102 300	163 575
7130	BRIDGE PILING					
7133	Concrete filled steel pipe piles (including concrete and reinforcement)					
	--Ø1200	1 062	m	1 500.00	1 593 000	
	--pile head Ø1200	45	nos	3 500.00	157 500	
	-transportation of equipment	1	nos	25 000.00	25 000	1 775 500
7140	FOUNDATIONS					
7141	Scaffolding and moulds	4 100	m^2	85.00	348 500	
7142	Reinforcement					
	-reinforcement bars A500HW	470 000	kg	2.00	940 000	
7144	Concrete works					
	-Acquiring of fresh concrete					
	--concrete K30	2 700	m^3	175.00	472 500	
	Casting under sea level	2 000	m^3	420.00	840 000	2 601 000
7150	ABUTMENTS					
7151	Scaffolding and moulds	1 000	m^2	90.00	90 000	
7152	Reinforcement					
	-reinforcement bars A500HW	38 400	kg	2.00	76 800	
7154	Concrete works					
	-Acquiring of fresh concrete					
	--concrete K35	320	m^3	200.00	64 000	230 800

Code	Description	Quantity	Unit	Unit cost Euro	Cost Euro	Total Euro
7160	INTERMEDIATE SUPPORTS					
7161	Scaffolding and moulds	40 000	m^2	95.00	3 800 000	
7162	Reinforcement					
	-reinforcement bars A500HW	1 188 000	kg	2.30	2 732 400	
7163	Pre-stressing and cable structures					
	-pre-stressing of cross beams	9 200	kg	10.40	95 680	
7164	Concrete works					
	-Acquiring of fresh concrete					
	--concrete K40/K50 - pylons	5 250	m^3	410.00	2 152 500	
	--concrete K40/K50 - piers	1 350	m^3	300.00	405 000	9 185 580
7170	SUPERSTRUCTURES					
7171	Scaffolding and moulds					
	-Mounting and demounting of moulds					
	--bridge deck	16 700	m^2	85.00	1 419 500	
7172	Reinforcement					
	-reinforcement bars A500HW	800 000	kg	2.00	1 600 000	
7173	Pre-stressing and cable structures					
	-cable structures					
	--stay cables	620 000	kg	10.40	6 448 000	
	--tie-down arrangement	20 000	kg	10.40	208 000	
7174	Concrete works					
	-Acquiring of fresh concrete					
	--concrete K40	4 000	m^3	300.00	1 200 000	
7176	Structural steel					
	-continuous girder	3 400 000	kg	4.50	15 300 000	
	-anchor boxes for cables	255 000	kg	5.00	1 275 000	
7179	Lining of surfaces					
	-impregnating of concrete surfaces	2 300	m^2	12.00	27 600	27 478 100

Code	Description	Quantity	Unit	Unit cost Euro	Cost Euro	Total Euro
7180	DECK SURFACE STRUCTURES					
7181	Water proofing					
	-rubberized sheet membrane insulation					
	--double	13 438	m^2	45.00	604 688	
7183	Asphalt pavement					
	-AB 12/70	13 438	m^2	11.00	147 813	
	-AB 20/120	13 438	m^2	14.00	188 125	940 625
7190	BRIDGE EQUIPMENT AND ACCESSORIES					
7191	Expansion devices					
	-bearings					
	--spherical or pot bearings					
	-5.0MN to 10.0MN movable	8	nos	4 000.00	32 000	
	-5.0MN to 10.0MN fixed/movable	8	nos	5 200.00	41 600	
	-wind bearings	4	nos	3 000.00	12 000	
	-expansion joints installed					
	-patented expansion joints					
	--movement >100mm	25	m	3 500.00	87 500	
	--movement 300mm					
	-approach slabs L=5m incl reinforcement	30	m^3	600.00	18 000	
7192	Drainage					
	-surface outlet pipes	70	nos	300.00	21 000	
	-drain pipes	700	nos	30.00	21 000	
7193	Protective equipment					
	-steel railings (hot dip galvanized)					
	--ribbed railing	2 160	m	350.00	756 000	
	--wind protective railing	80	m	350.00	28 000	
7194	Other equipment and accessories					
	-access gantry	1	nos	400 000.00	400 000	
	-access facilities (ladders, hatches)	1	nos	80 000.00	80 000	
	-navigation and aviation lights	1	nos	12 000.00	12 000	
	-footings for lighting posts					
	--lighting posts Ø 159 - 240	22	nos	1 000.00	22 000	
	-pipe works for electric cables					
	--pipes Ø≤50 JP50	2 160	m	10.00	21 600	
7196	Monitoring system					
	-weather station, temperature of surfacing, cable vibrations, camera	1	nos	180 000.00	180 000	1 732 700

Code	Description	Quantity	Unit	Unit cost Euro	Cost Euro	Total Euro
	Construction cost					44 107 880
600	Over head costs for bridge site	25 %				11 026 970
	Contractor's design of temporary works	1 %				441 079
	Bridge cost					55 575 929
	Miscellaneous items / contingency	15 %				8 336 389
	Round off					-318
	Bridge cost, construction					63 912 000
	Detailed design and tender documents	1	nos	3 250 000.00	3 250 000	
	Construction supervision	1	nos	3 750 000.00	3 750 000	7 000 000
	BRIDGE COST, TOTAL					70 912 000

Finnish Road Administration, Turku Road Region

Evaluation of Airisto Stay Cable Bridge

Ship Collision Risk Assessment and Estimate of Protection Structures

September 2008

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Evaluation of Airisto Stay Cable Bridge

Ship Collision Risk Assessment and Estimate of Protection Structures

September 2008

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Version	0
Date of issue	16 September 2008
Prepared	ROUL, KRSG
Checked	OKBL, IJ
Approved	TVE

Table of Contents

1 Scope

The scope of the present study is to asses the risk of ship impact for the existing design of the Airisto cable stayed bridge with 440 m main span between Parainen (east) and Nauvo (west), Finland.

The study comprises a rough estimate of foundation capacities of the critical pylons and pier, modelling of ship traffic leading to the ship collision risk assessment. Following the ship collision risk assessment a layout of protection structures is presented.

The assessment is intended to supplement the cost estimate of the cable stayed bridge described in Report No. P69597-A-R01.

2 Summary of Review Findings

The load case ship impact to piers and pylons and mast impact to the girder has to be considered in the design of the bridge.

The risk of ship impact of Airisto Cable Stayed Bridge is deemed to be acceptable only if additional measures are taken (increase of horizontal foundation capacity and/or additional protection measures). Based on the provided information, a normal ship traffic distribution was assumed in this study.

Based on the risk analyses and the preliminary design of protection islands it is recommended to reconsider the foundation concept. Caisson foundations for pier T4 and pylon T6 could be appropriate. They are suitable for the actual water depth and can be designed to resist high horizontal impact forces.

For a refined assessment of the risk of ship impact the assumption on the ship traffic distribution should be based on the real ship traffic at the bridge location. However, this is outside the scope of the present study.

3 Basis

3.1 General

The ship risk analysis is a tool for the assessment of the bridge arrangement. Generally, the risk analysis includes bow impact of ships against pylons and piers and deckhouse impacts against girders. On that basis, a risk analysis provides a sound decision basis for determining the need for additional protection measures.

The assessment of the risk of ship impact follows closely the AASHTO guideline [1], because it provides a practically applicable guideline based on the same probabilistic approach as Eurocode. Moreover, the analysis bases on experiences from the Great Belt project.

Impact forces are calculated according to the method proposed by Pedersen et al. [2]. The majority of ships sailing in the Baltic Sea can be assumed to be ice-strengthened. For ice-strengthened ships Pedersen et al. [2] gives more reasonable values than the AASHTO formula.

Basis of the risk assessment received from the client are:

- Drawing 'Airisto.dwg' received 14.08.2008
- Drawing 'siltapaikan_vaylatiedot.dwg' received 21.08.2008
- Information about ship traffic received by e-mail (primarily 03 & 04.09.2008)

The elevation of the general bridge arrangement is shown in Figure 1.

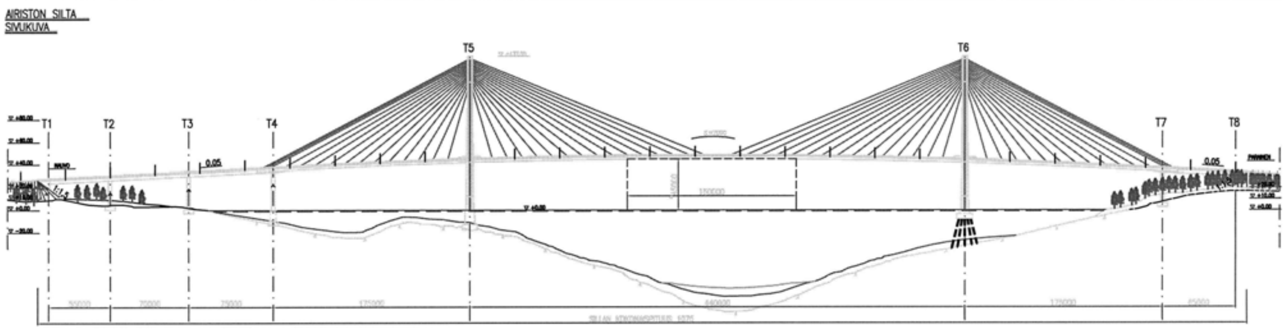


Figure 1 Elevation of general bridge arrangement.

In the case of the Airisto Cable Stayed Bridge both pylons (T5 and T6) and the first pier in the back span to the Nauvo (west) side (T4) are exposed to the risk of ship impact and as a result of this a ship risk impact analysis needs to be carried out.

The navigational channel has a width of 150 m and is shifted from the centre of the main span by approximately 10 m to the Nauvo (west) side. The angle of the navigational channel to the bridge alignment is assumed to be 90°. The vertical clearance is 45 m in respect to ±0.0 m water level. Two-way navigation is assumed.

The provided minimum/average/maximum water level is -0.85/-0.12/+1.2 m. The water current is not significant, i.e. less than 1 knot.

Four harbours are located in the vicinity of the bridge location. Those are the harbours of Turku, Naantali, Parainen and Dragsfjärd, see Figure 2.

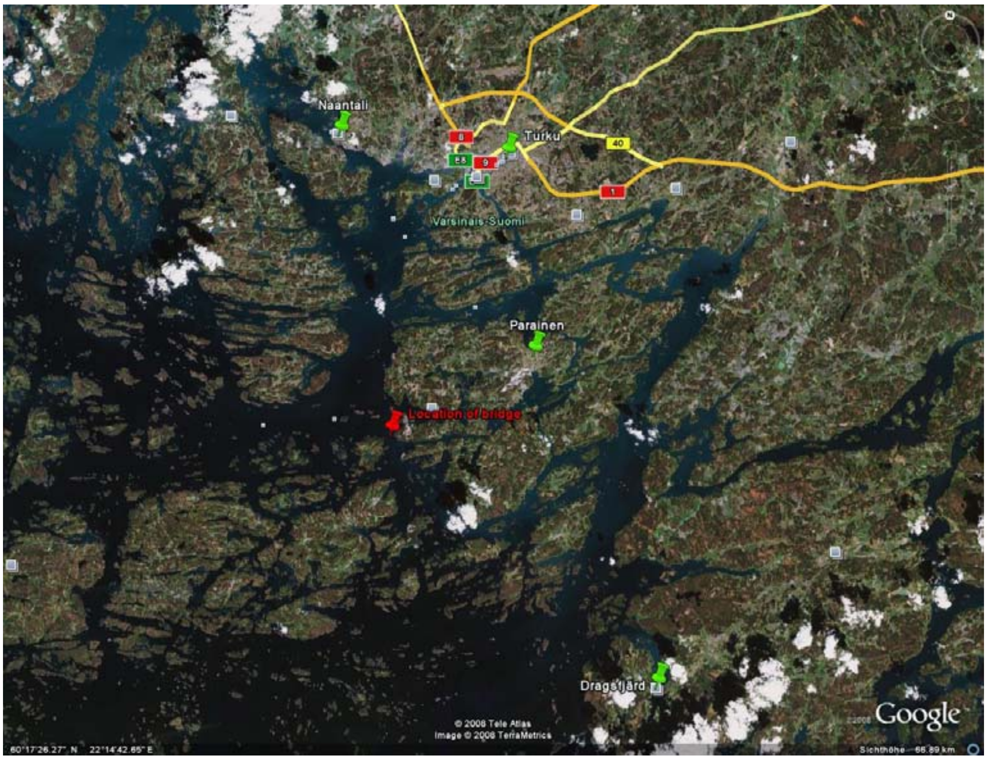


Figure 2 Harbours in the vicinity of the proposed bridge location.

The proposed bridge location is part of an area which is controlled by a Vessel Traffic Management System (VTS). On commercial ships there is always a pilot on board. However, ships navigating regularly have their own pilot especially for that route.

3.2 Ship Traffic

3.2.1 Ship Traffic Distribution

The information about the ship traffic distribution from the client comprises the following information:

- The depth of the channel allows the navigation of ships having a draught of 7.5 m. The minimum depth is therefore about 9 m.
- Passages annually between 1450 and 3000 ships together for both directions (50% of the total ship number in each direction).
- Ship size up to 10 000 DWT (maximum: 11 000 DWT, average: 4300 DWT)
- Cargo ships: maximum length from 140 m to 170 m, maximum breadth from 20 m to 27 m
- Cruiser (passenger ships): maximum length 200 m, maximum breadth 32 m
- Maximum/average navigation speed: 15 knots/9-13 knots

Additionally, the ship traffic distribution has been analysed by ship data from Naantali and Turku Port Authority (http://www.naantali.fi/satama/, http://www.port.turku.fi/portal/port/). Such information is not available for the ports of Parainen and Dragsfjärd. However, the limited available data can not be used for the definition of the ship traffic distribution, but the information found was useful to confirm the data listed above. The findings (annual number of ships, average DWT, length) correspond to the given information.

Finally for the risk analysis, a conservative normal ship traffic distribution is chosen, meaning that every DWT class contains the same number of ships. A ship property database originally created for the Great Belt Bridge (Denmark) is used to assign each DWT class appropriate ship properties. In terms of ship classes only 'Passenger' and 'Other' ships are considered in the present study. Passenger ships with up to 10 000 DWT and Other ships with up to 14 000 DWT are considered in the risk analysis.

The modelling of the geometric probability follows closely the AASHTO guideline. Herein, the geometric probability is modelled based on a normal distribution with a standard deviation equal to the overall length LOA (here: LOA = 170 m). In accordance with our practice, this model is improved by taking into account ships navigating randomly (e.g. due to engine break down or steering failure). The latter are modelled based on a uniform distribution between the shores. It is also considered that this adds robustness to the modelling of the geometric probability. It is considered that 99% of the ships sail normally distributed and 1% of the ships sail randomly distributed.

3.3 Foundation Capacity

3.3.1 General and Summary of Results

For the check of the acceptance level of the risk of ship impact one has to estimate the horizontal capacity of the foundations. In the following the calculation of the horizontal foundation capacity for the pier T4 and pylons T5 and T6 is described. It should be noted that no detailed geotechnical information is available, and consequently the properties of the rock / soil have to be assumed.

The estimated horizontal foundation capacities that are used for the check of the risk of ship impact are summarized in Table 1.

Table 1 Estimated horizontal foundation capacities.

	Pier T4	Pylon T5	Pylon T6
Horizontal foundation capacity [MN]	8.6	75.1	33.0

3.3.2 Slab foundations of Pier T4 and Pylon T5

The horizontal foundation capacity of the slab foundations are estimated by means of global equilibrium for rotation. Assumptions for the foundation depth as well as for the dimensions of the slabs are shown in Table 2.

The ultimate limit state is defined by maximum admissible stresses of 10 MPa transmitted to the rock. This value, which could also be in the range of 5 to 20 MPa, is assumed to be conservative considering an accidental loading situation without safety factors.

For the vertical loads, only dead load has been taken into account. For Pier T4 no loads are assumed to be transmitted from the girder to the pier, due to possible load cases where these loads could be compensated. From vertical loads and normal distributed soil pressure, an admissible eccentricity of the vertical loads is calculated, which leads to the maximum horizontal force (horizontal foundation capacity) at water level.

Table 2 Summary of input values and horizontal foundation capacities.

	Pier T4	Pylon T5
Assumed vertical load [MN]	16.4	161.3
Foundation depth [m]	10.8	18
Foundation length [m]	7	13
Foundation width [m]	11.5	18
Admissible eccentricity [m]	5.66	8.38
Horizontal foundation capacity [MN]	8.6	75.1

3.3.3 Pile foundation of Pylon T6

The foundation of pylon T6 consists of 45 piles made of reinforced concrete in a steel casing, Figure 3. The piles have a diameter of 1.2 m and are 23 m long. The pile cap has a width of 15.2 m and a length of 13 m. In transverse direction (direction of ship impact) the last seven piles (two pile rows on each side out of totally 13 rows) are assumed to have an inclination of 1:10. Admissible stresses on the rock are assumed to be 10 MPa.

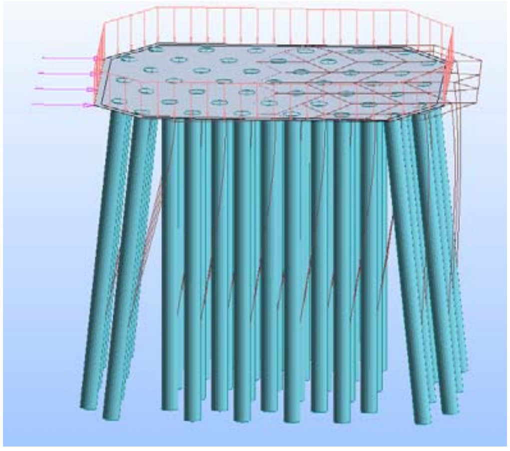


Figure 3 Arrangement of pile foundation for pylon T6

The foundation capacity is limited due to the bending capacity of the piles. The piles have to be fixed in the rock, where an intrusion of about three times the pile diameter ($3 \cdot 1.2 = 3.6$ m) is assumed. Along the lateral area of the piles shear forces of 1.2 MPa are allowed for both tension and compression in a pile. A reinforcement ratio of 2.5% (200 kg/m^3) is assumed for the piles. Contributions of the steel casings are not taken into account. The steel casing will not be sufficiently well anchored at the critical places (penetration of the casing into the rock and into the pile cap slab missing). The normal compressive force of each pile is limited to 27.5 MN by the rock strength, whereas the normal tension force is limited to 12 MN by the pile reinforcement.

The normal forces in the piles are calculated by means of a non-linear FE-model (geometrically non-linear) and depend on the stiffness of the pile cap and on the magnitude of the horizontal force. Therefore, an iterative approach is needed until the ultimate capacity is acting as horizontal force. The bending capacity for each pile is set according to the corresponding normal force.

The total bending capacity of the piles is 276.7 MNm, which corresponds to a horizontal force of 24.1 MN acting on the pile cap. The horizontal component of the inclined piles is 8.5 MN and is taken from the actual normal force in each pile. Both components added up result in the horizontal foundation capacity of 33 MN.

Since this approach implies that all piles reach yielding for the maximum capacity, the horizontal displacement has to be checked. The resulting displacement is 180 mm and is, for the purpose of the present investigation, assumed to be acceptable.

4 Risk of Ship Impact

4.1 General

The result of the risk analysis is expressed by two values: probability of failure and probability of collision.

The vertical clearance profile of the Airisto Cable Stayed Bridge is adequate for the ships considered in this study. The maximum height of these ships is summarized in Table 3. The deckhouse height is below the girder that provides the minimum clearance of 31.9 m in the side span.

Table 3 Maximum heights of ships considered in this study.

Maximum height [m]	Deckhouse	Mast
Other (< 14 000 DWT)	29.0	38.0
Passenger (< 10 000 DWT)	30.0	43.1

The results of the risk analysis show that there is no contribution from deckhouse impact. However, the girder shall be designed for mast impact.

According to AASHTO guideline [1], the Airisto Cable Stayed Bridge can be categorised as a critical bridge and thus the maximal probability of failure shall be taken as $1 \cdot 10^{-4}$/a (one failure in 10 000 years).

Because of the high variation in input values such as ship speed, number of ships and influence of horizontal foundation capacities a sensitivity study has been conducted.

4.2 Vessel Speed

The vessel speed is varied in a range between 9 knots and 13 knots. The water current of less than 1 knot is neglected. 3000 ships (1500 in each direction) and horizontal foundation capacities as stated in Table 2 are considered. The results are shown in Figure 4.

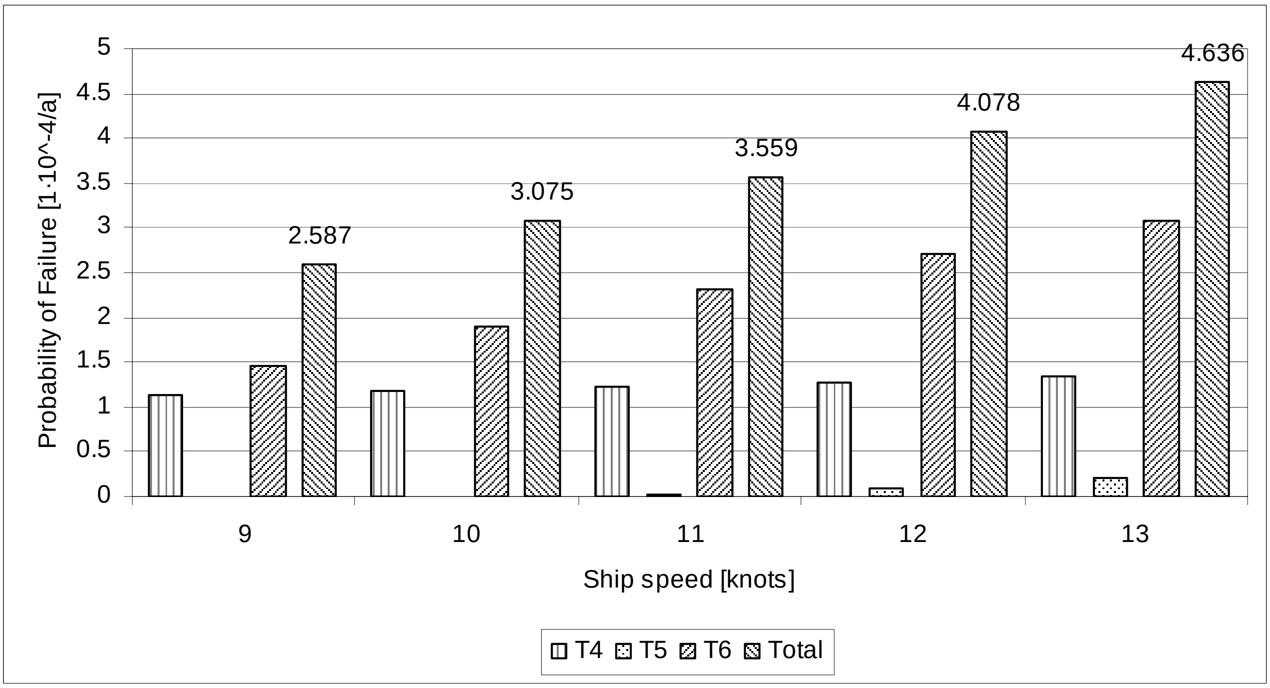


Figure 4 Probability of failure for different vessel speeds (foundation capacities see Table 2, 3000 ships/year).

The total probability of failure is in all cases higher than $1 \cdot 10^{-4}$/a and the risk of ship impact is therefore not acceptable.

The pylon T5 has sufficient horizontal capacity, so that its contribution to the risk of ship impact is small. The risk of ship impact is for each the pier T4 and pylon T6 alone not acceptable.

The total probability of failure increases with increasing ship speed, but at the same time the ratio from each structural component T4 to T6 changes. The pylon's contribution to the total risk increases with increasing ship speed.

The probability of collision is independent of the vessel speed. The values are given in Table 4.

Table 4 Probability of collision.

Probability of collision [10^{-4}/a]	T4	T5	T6	Total
3000 ships/year	14.8	100.9	93.9	209.6

The probability of collision shows that mainly the pylons T5 and T6 are exposed to ship collision. The probability of collision for pier T4 is rather small but at the same time the probability of failure, see Figure 4, is quite high compared to the pylons. This is because of the low horizontal foundation capacity of pier T4. The mismatch between the probability of collision and the probability of failure can be improved by increasing the horizontal foundation capacity and/or additional protection measures.

4.3 Number of Passages

The total number of passages is varied in a range between 1500 and 3000 (50%of the total ship number in each direction). The ship speed is 9 knots and horizontal foundation capacities as stated in Table 2 are considered. The results are shown in Figure 5.

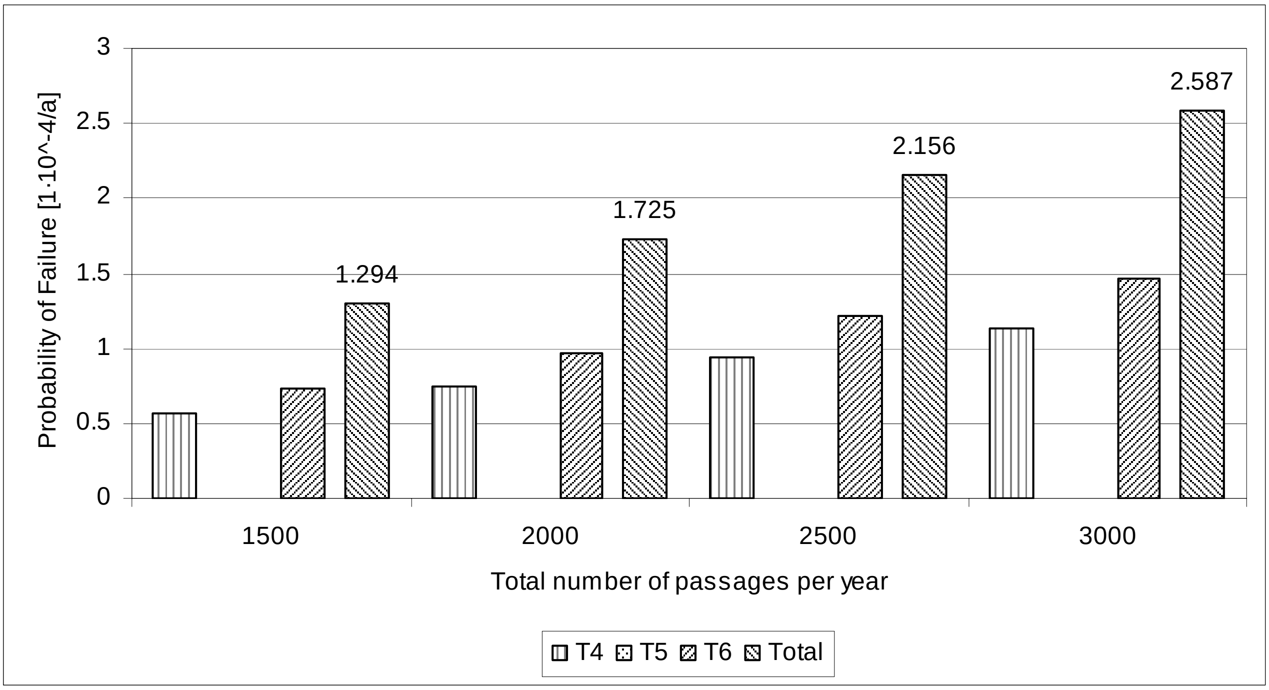


Figure 5 Probability of failure for different vessel speeds (foundation capacities see Table 2, ship speed 9 knots).

Figure 5 shows that the risk of ship impact is not acceptable according to AASHTO [1] , i.e. $1 \cdot 10^{-4}$/a, even for the slowest ship speed and the lowest number of ships per year and for the ship traffic distribution assumed in this study.

The total probability of failure increases linearly with increasing number of passages. The influence of the number of passages has the same influence on all structural components.

The probability of collision depends as expected on the number of passages, Table 5. The correlation between these two values is as well linear.

Table 5 Probability of collision.

Probability of collision [10^{-4}/a]	T4	T5	T6	Total
3000 ships/year	14.8	100.9	93.9	209.6
2500 ships/year	12.4	84.1	78.3	174.7
2000 ships/year	9.9	67.2	62.6	139.7
1500 ships/year	7.4	50.4	47.0	104.8

Again, the pylons are most exposed to ship collision but the probability of failure of pier T4 is relatively high in comparison to the pylons T5/T6 due to the low horizontal foundation capacity of the pier.

4.4 Ship Impact Force

The maximum ship impact forces applied in the calculations are summarised in Table 6. The maximum ship impact force results for a ship (of type Other) with an overall length of 154 m.

Table 6 Maximum ship impact forces for different ship speeds.

Ship speed [knots]	9	10	11	12	13
Maximum impact force [MN]	67	74	82	89	96

The magnitude of the horizontal foundation capacity of pylon T5 (74 MN) seems to be sufficient for ship impact, whereas it is well below the maximum impact force for pier T4 (8.6 MN) and pylon T6 (33 MN), see Table 2.

4.5 Horizontal Foundation Capacity

The horizontal foundation capacity of pylon T6 has to be increased to fulfil the risk of ship impact if no additional protection measures are taken. For this reason the horizontal foundation capacity of pylon T6 is included in the parameter study.

The calculation has been conducted with horizontal foundation capacities of 50 MN, 75 MN and 100 MN, for ship speeds of 9 and 13 knots and 3000 ships/year. The results for the total probability of failure are shown in Figure 6.

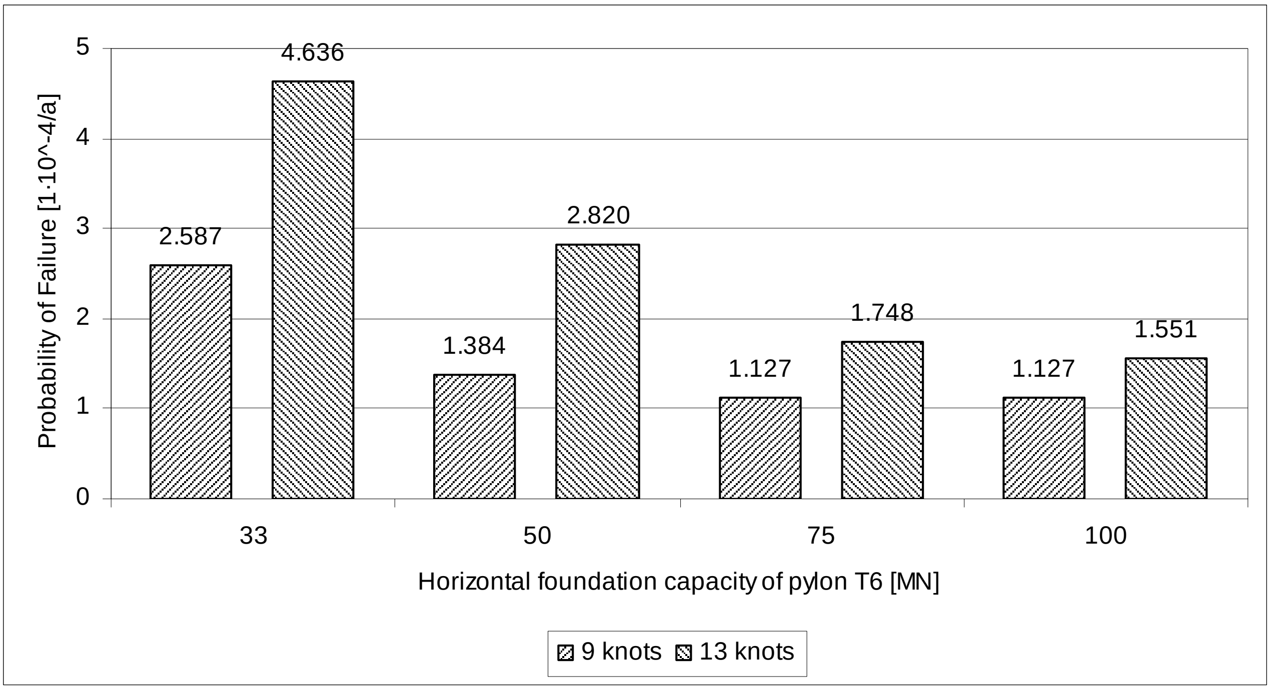


Figure 6 Influence of the horizontal foundation capacity of pylon T6 on the total risk of ship impact

Increasing the horizontal foundation capacity of pylon T6 has a strong effect on the risk of ship impact. Increasing the capacity from 33 MN to 50 MN almost reduces the probability of failure to half. However, for a ship speed of 9 knots the increase of the horizontal capacity from 75 MN to 100 MN has no effect. The horizontal foundation capacity of pylon T6 of 75 MN is already higher than the maximum ship impact force for 9 knots, i.e. 66.7 MN see Table 6, and does therefore not contribute to the risk of ship impact.

Concerning costs, one can also see from Figure 6 that the effectiveness of an increased horizontal foundation capacity reduces with increased horizontal foundation capacity.

However, the risk of ship impact is still not acceptable according to AASHTO [1], i.e. $1 \cdot 10^{-4}$/a for the cases calculated in Figure 6. That is mainly due to the very low horizontal foundation capacity of pier T4, i.e. 8.6 MN. The horizontal capacity of pier T4 has to be increased as well even the number of ships per year is less than 3000 ships/year.

For the worst case (ship speed 13 knots and 3000 ships/year) the horizontal foundation capacity of pier T4 shall additionally be increased to 25 MN (25/75/100 MN for foundations of T4/T5/T6) in order to reach an acceptable risk of ship impact according to AASHTO [1], i.e. $1 \cdot 10^{-4}$/a, see Table 7.

Table 7 Probability of failure.

Probability of failure [10^{-4}/a]	T4	T5	T6	Total
3000 ships/year	0.701	0.210	0	0.911

5 Additional Protection Measures

5.1 General

Additional protection measures are an option to increase the acceptance level of the risk of ship impact. In the following it is studied how a collision of ships to piers and pylons is avoided by means of protective structures and/or in combination with the residual force transferred to the pier or pylon being lower than the horizontal foundation capacity.

In this study, protection islands for the pier T4 and the pylon T6 are investigated more closely.

5.2 Protection Island

5.2.1 General, Design Parameters

In the following, the main assumptions (e.g. the design ship) used for the design of protection islands for the Airisto Cable Stayed Bridge are summarised. The calculations conducted hereafter present an estimate for the effectiveness of the protection islands based on these assumptions.

The protection island design was reviewed using a software programme. A soil (friction) material was considered in the analysis. This software has successfully been applied for similar evaluations of infrastructure projects such as 'The Great Belt East Bridge' (Denmark), 'New Sydney Lanier Bridge' (USA), 'Busan-Geoje Fix Link' (South Korea) and 'Cooper River Bridge at Charleston' (USA). The theoretical and experimental basis for the program is described in [3].

The protection islands shall:

- Prevent vessels from colliding with a bridge component (stopping effect)
- Reduce the bow impact force transferred to the structure by the soil-structure interaction (load transfer effect).

Following, the design criteria are:

- The remaining distance between the vessel and the bridge component must be bigger than zero.
- The residual impact force must be smaller than the horizontal foundation capacity.

Ships considered in the calculation are summarized in Table 8.

Table 8 Data of ships that were used for the review of the protection island design.

#	Name	Lloyds Nr	Ship Type	DWT	Displacement	Length	Breadth	Draught	GT
				[t]	[t]	[m]	[m]	[m]	[t]
1	FINNCLIPPER	9137997	Passenger	8681	21200	188.1	29.3	6.5	29841
2	SUPERFAST IX	9211509	Passenger	5915	19235	203.3	25.4	6.7	30285
3	SILJA EUROPA	8919805	Passenger	4650	26019	201.78	32.6	6.8	59912
4	PASILA	9113018	Other	13367	18678	137.1	21.6	8.2	10098
5	FINNPULP	9212644	Other	10300	21718	184.8	26.5	6.8	25654

Ships in Table 8 were selected based on the port's ship information (Naantali, Turku) mentioned in section 3.2 and in accordance with the ship traffic assumed in the risk analysis (maximum DWT, maximum draught). For a more detailed assessment it needs to be confirmed, whether these or larger ships are expected to cross the proposed bridge location.

The displacement of a ship is the most important property for the residual impact load on a bridge component. Also the loading situation of a ship which influences the draught is of importance. A ship might have a smaller remaining distance to the bridge component if it impacts the island not over the island's full height but more at the top (ship with smaller draught). In the calculations, ballasted and loaded ship constellations expressed by a relative draft of 60% and 100%, respectively were considered.

Many ships such as the ones in Table 8 have bulbs so that the bow is more pointed. Therefore, the bow factor is varied between 60% and 100%. A bow factor of 100% considers the full breadth of a ship (no bulb).

According to AASHTO [1], a reduced ship impact force has to be taken into account in longitudinal direction of the bridge for ships colliding with the bridge structure in angles different from 90° to the longitudinal bridge axis. For the design of the protection islands, a ship speed of 13 knots in transverse direction (90°) and 60% of that value, i.e. 7.8 knots, in longitudinal (0°) direction of the bridge are taken into account.

For the check of the design criteria above, the estimated horizontal foundation capacities in Table 1 were used for the transverse direction. The foundation capacities for a force in longitudinal direction are not part of the present analysis.

For the design of the protection islands in longitudinal direction it is assumed that the residual impact force in longitudinal direction must be smaller than in transverse direction. This assumption refers to a lower limit consideration for the dimensions of the protection island in longitudinal direction.

The minimum horizontal foundation capacity in longitudinal direction that has to be provided by the design is equal or larger than the maximum residual impact force in longitudinal direction calculated hereafter. Otherwise, the dimensions in longitudinal direction must be increased.

5.2.2 Grounding Simulation

Geometric properties and results

The geometric input parameters for the grounding simulation are illustrated in Figure 7 and summarized for the pier T4 and the pylon T6 in Table 9.

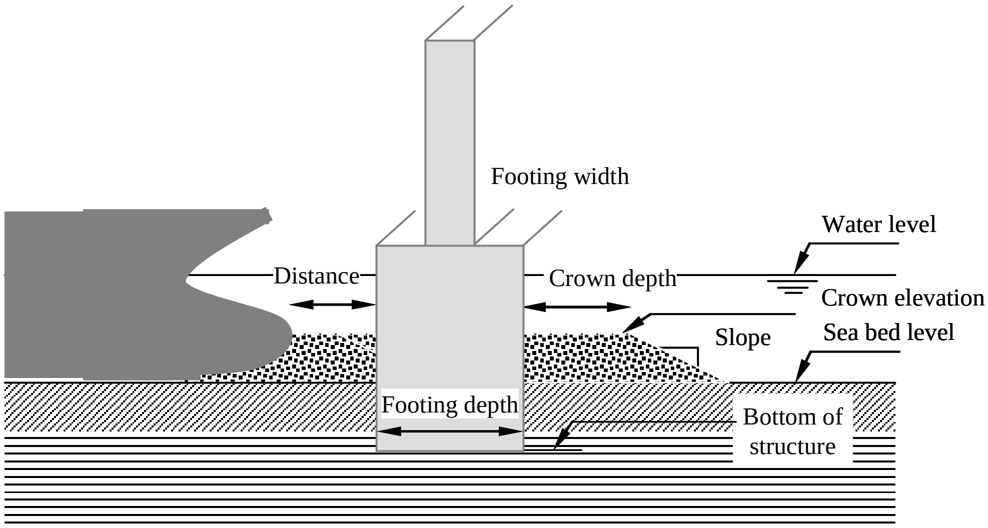


Figure 7 Geometrical overview of ship grounding on protection islands.

Table 9 Geometrical input parameters for ship grounding simulation.

Component	Pier T4 (longitudinal/transverse)	Pylon T6 (longitudinal/transverse)
Slope	1:1.5	1:1.5
Crown depth [m]	10/10	7.5/10
Crown elevation [m]	1.5	1.5
Footing width [m]	11.5/7	15.2/13
Footing depth [m]	7/11.5	13/15.2
Sea bed level [m]	-9.7	-9.7
Bottom of structure [m]	-26.6	-30.2

The results from the analysis for the defined parameters are summarized in Table 10 and Table 11.

The proposed protection islands for pier T4 and pylon T6 are visualised in Figure 8.

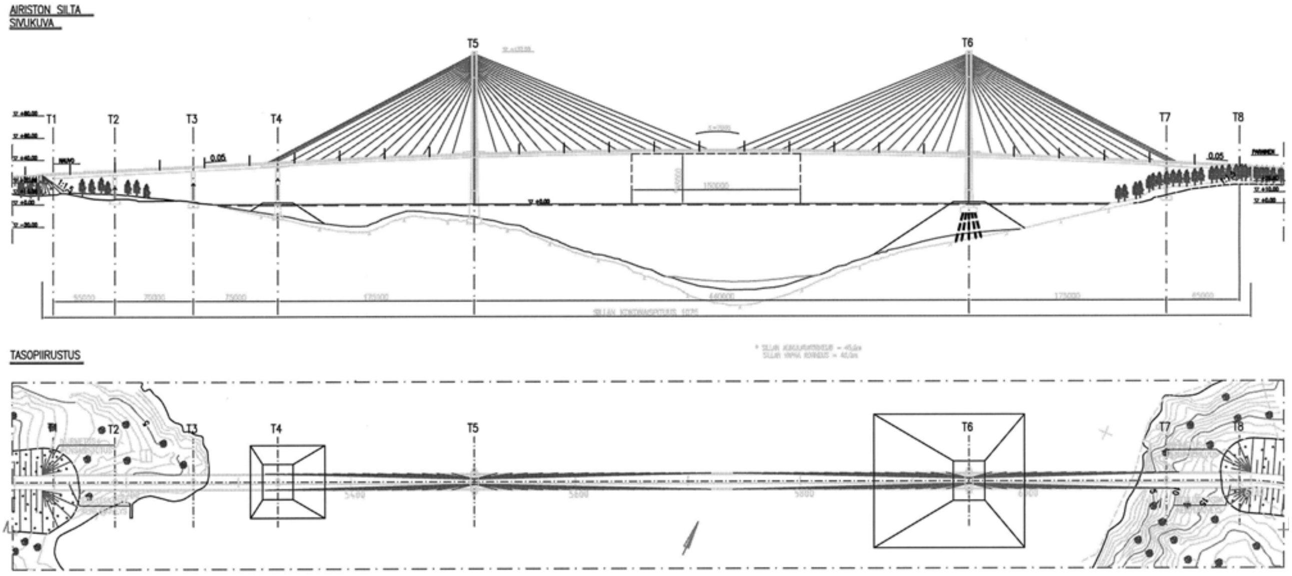


Figure 8 Airisto Cable Stayed Bridge including protection islands for pier T4 and pylon T5

Pylon T6

In general, it can be concluded that the protection island for pylon T6 fulfil the design criteria defined in section 5.2.1 when a horizontal foundation capacity in longitudinal direction of at least 25.2 MN can be provided. The horizontal foundation capacity in transverse direction, i.e. 33 MN, is larger than the maximum residual impact force, i.e. 27.4 MN. The remaining distance is always larger than zero.

The volume of the proposed protection island (shape simplified to an obelisk) is 220000 m^3.

Table 10 Minimum distance and maximum residual impact force acting on the foundation.

Pylon T6_longitudinal					
Finnpulp, Silja Europa	**Distance** [m]		Finnclipper	**Residual Force** [MN]	
	relative draft			relative draft	
Bow factor	60	100	Bow factor	60	100
60	5.4	7.1	60	15.9	25.2
100	6.7	8.7	100	15.2	20.9
Pylon T6_transverse					
Finnpulp, Silja Europa	**Distance** [m]		Silja Europa, Pasila	**Residual Force** [MN]	
	relative draft			relative draft	
Bow factor	60	100	Bow factor	60	100
60	0.3	2.3	60	12.9	25.4
100	3.4	5.6	100	14.3	27.4

Pier T4

The design of the protection island for pier T4 shows again, that the horizontal foundation capacity in transverse direction is by far too small. In order to fulfil both design criteria defined in section 5.2.1, the crown depth should be larger than 12.5 m.

Pier T4 is much less exposed to ship collision compared to pylon T6, but the protection island for pier T4 has the same or larger size than the pylon T6. The visual difference of the protection island's size in Figure 8 is mainly created by the water depth.

However, the horizontal foundation capacity in transverse direction should be increased as it has already been concluded from the risk assessment, see section 4.2 and 4.5, respectively.

The proposed protection island for pier T4 fulfils the design criteria, if the horizontal foundation capacity in transverse direction would be doubled to $2 \cdot 8.6 = 17.2$ MN, see Table 1, and if a horizontal foundation capacity in longitudinal direction of at least 10.2 MN can be provided. The remaining distance is always larger than zero.

The volume of the proposed protection island (shape simplified to an obelisk) is 26400 m^3.

Table 11 Minimum distance and maximum residual impact force acting on the foundation.

Pier T4_longitudinal					
Finnpulp, Silja Europa	**Distance** [m]		Silja Europa	**Residual Force** [MN]	
	relative draft			relative draft	
Bow factor	60	100	Bow factor	60	100
60	7.9	9.6	60	6.6	10.2
100	9.2	11.2	100	5.5	6.7

Pier T4_transverse					
Finnpulp, Silja Europa	**Distance** [m]		Finnpulp, Silja Europa, (Pasila)	**Residual Force** [MN]	
	relative draft			relative draft	
Bow factor	60	100	Bow factor	60	100
60	0.3	2.3	60	9.7	12.2
100	3.4	5.6	100	(5.8)	9.4

The following should be noted in relation to installation of protection structures:

- A relatively high additional costs for additional protection structures that are not part of the principal structure such as fundaments, girders, pylons, etc.
- Additional environmental impact of e.g. a large protection island in the sea
- More narrow navigational channel
- Huge protection islands due to large water depth (pylon T6) or too small horizontal foundation capacities (pier T4)
- The presented outline is a basis for further optimisation.

5.2.3 Cost estimate

Assuming a unit cost of 20 €/m^3 for the friction material in the protection structures, including installation cost, the total cost of the protection structures for pier T4 and pylon T6 is estimated to 4.9 million €, plus overhead and contingency.

Based on the risk assessment conducted for Airisto Cable Stayed Bridge and results of the protection structure design, it might be more favourable to adjust the horizontal foundation capacities of pier T4 and pylon T6. This option is briefly investigated in the following.

5.3 Review of foundation concept

The horizontal foundation capacity should be roughly in the magnitude of 80 to 100 MN for the pylon foundations and 25 MN for the pier foundation depending on the ship traffic distribution, the ship speed, etc.

The following sections evaluate the potential of the existing foundations based on the assumptions given in section 3.3.

5.3.1 Existing foundations

Slab foundation at pier T4 and pylon T5

The horizontal foundation capacity can generally be increased by increasing the width of the foundation slab. The results of this study are shown in Figure 9 and Figure 10.

For pier T4 the hollow pier section could be completely filled by heavy fill material to add dead load. This would increase the capacity to about 17 MN for a foundation width of 16 m, see Figure 9.

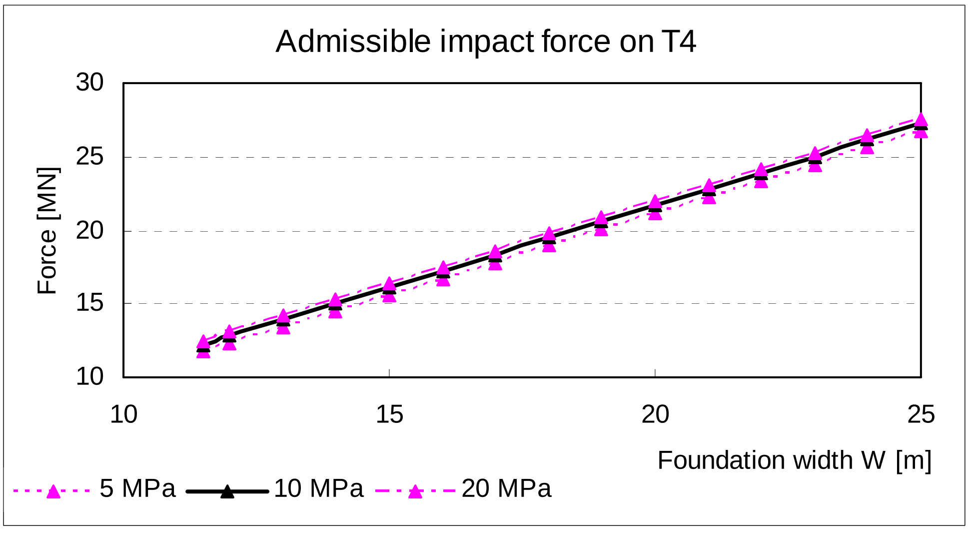


Figure 9 Increase of horizontal capacity for slab foundation of pier T4.

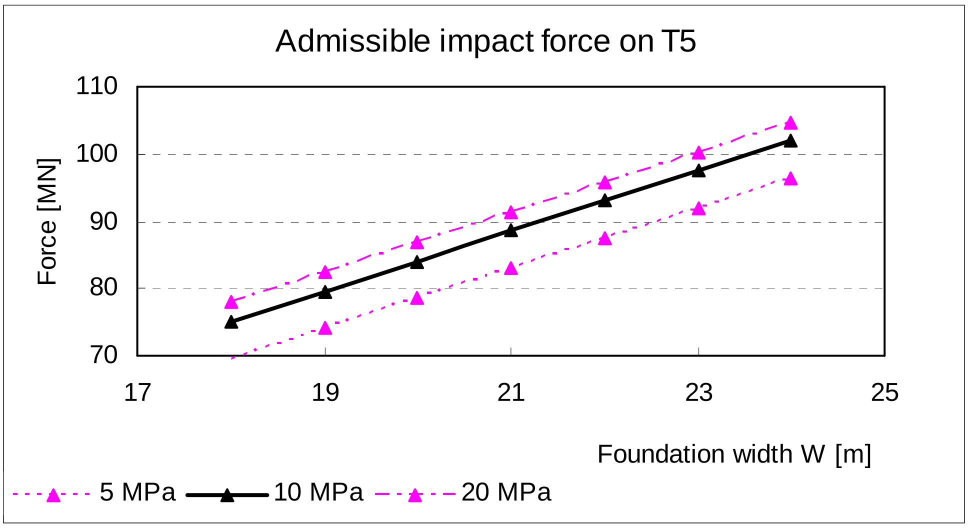


Figure 10 Increase of horizontal capacity for slab foundation of pylon T5.

To increase of the horizontal foundation capacity of pier T4 to 25 MN leads to an unreasonable foundation width (approximately three times larger), whereas the increase of the horizontal foundation capacity of pylon T5 above 75 MN can be realised with the existing foundation type (to 100 MN approximately 1.33 times larger foundation).

Pile foundation at pylon T6

An increase of the horizontal foundation capacity can be achieved by inclining more piles. As a comparative study, the last two rows (7 piles) are inclined with 1:6 and the next two rows (additional 7 piles) with 1:10. The foundation with the new pile arrangement has a horizontal foundation capacity of 42.1 MN. It is estimated that the horizontal foundation capacity of the pile foundation could ultimately be increased to approximately 50 MN by inclining more piles (e.g. 7 piles with 1:4, 7 piles with 1:6 and 7 piles with 1:8).

The pile foundation has not enough potential to increase the horizontal foundation capacity of pylon T6 to an adequate level.

5.3.2 Improved foundation design

The necessary increase of the horizontal foundation capacity requires a new design for pier T4 and especially for pylon T6.

Caisson foundations could be considered for pier T4 and Pylon T6. A similar caisson foundation, as would be needed for the Airisto Cable Stayed Bridge with a horizontal foundation capacity of 80 to 100 MN has been designed for the 'Busan-Geoje Fix Link' (South Korea), which is currently under construction. The water depth for the Busan-Geoje caisson foundation is -30 m, which is comparable to the Airisto Cable Stayed Bridge.

A sketch of a caisson for pylon T6 is shown in Figure 11. The estimated quantity of concrete is in the order of 5000 m^3 with an assumed reinforcement of about 1000 tonnes.

A separate study is require to provide more details including cost estimate for foundation on a caisson, which is outside the scope of the present study.

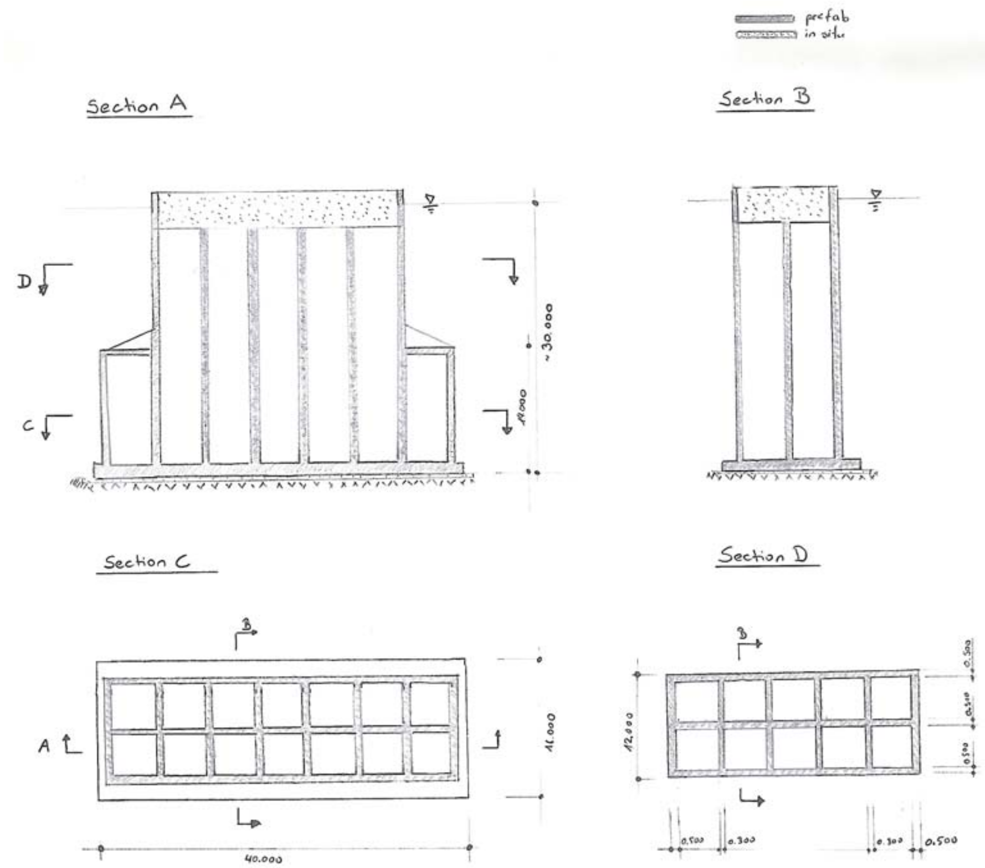


Figure 11 Caisson solution for the foundation of pylon T6.

6 Conclusions

The load case ship impact to piers and pylons and mast impact to the girder has to be considered in the design of the bridge.

The risk of ship impact of Airisto Cable Stayed Bridge is based on the aforementioned assumption on the ship traffic distribution deemed to be acceptable only if additional measures are taken.

In order to satisfy the limits for the risk of ship impact, i.e. $1 \cdot 10^{-4}$/a, it can be considered to increase the horizontal foundation capacity and/or take advantage of additional protection measures (such as protection islands, dolphins, etc.).

Increasing the horizontal foundation capacity of a structural member so that it exceeds the maximum ship impact force reduces the risk contribution of this structural member to zero, but might not be the most cost effective option. For 3000 ships/year and a maximum ship speed of 13 knots horizontal foundation capacities of approximately 25/75/100 MN should be provided for foundations T4/T5/T6.

Protection islands have been discussed in detail. However, a number of problems arise in relation to the large water depth (pylon T6) and the small foundation capacity (pier T4). Based on the risk analyses and the design of protection islands it is recommended to reconsider the foundation concept in order to increase the horizontal foundation capacities to a reasonable level in comparison to the expected ship impact forces. Caisson foundations for pier T4 and pylon T6 could be an appropriate solution. They can be founded in deep water and designed for high horizontal impact forces.

Alternatively, the position of the critical pylons and piers may be changed by increasing the span.

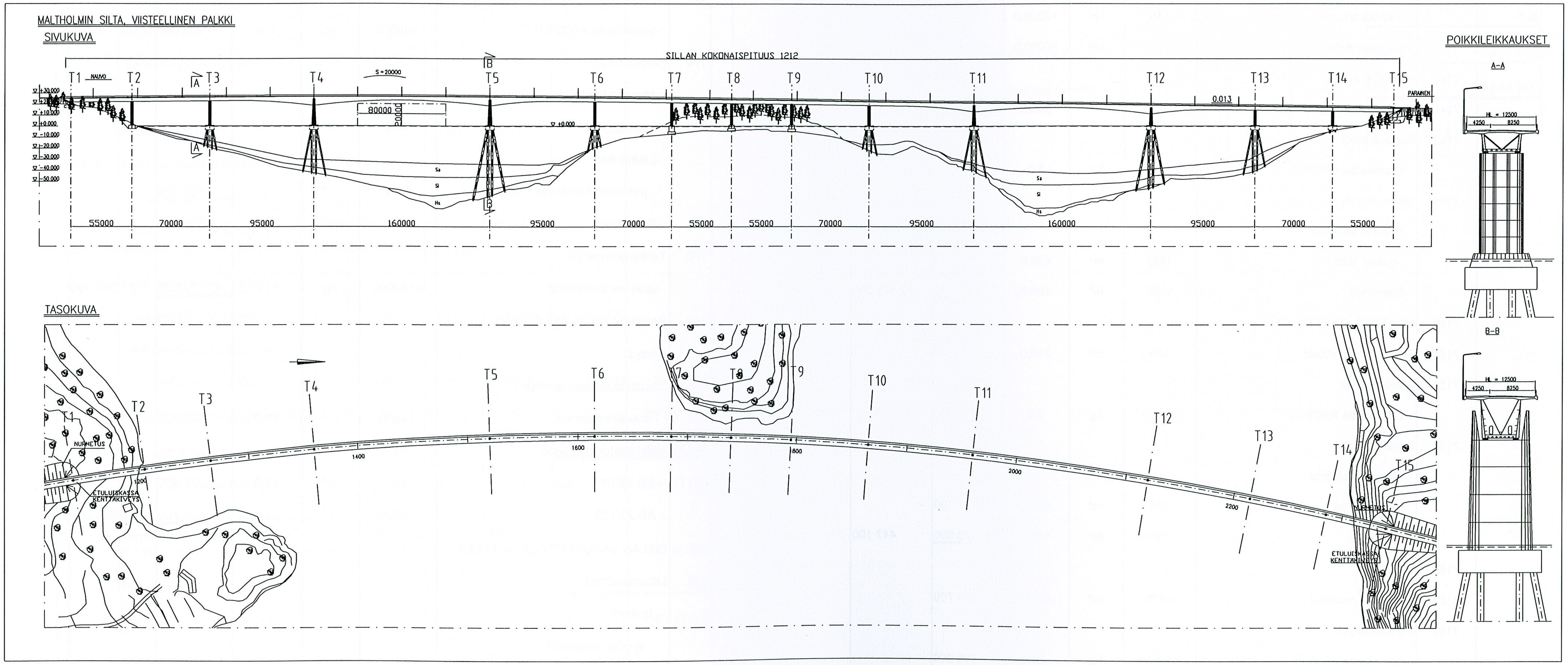
For a refined assessment of the risk of ship impact the assumption on the ship traffic distribution should be based on the real ship traffic at the bridge location.

7 Literature

[1] AASHTO, “Guide Specification and Commentary for Vessel Collision Design of Highway Bridges”, American Association of State Highway and Transportation Officials, 1991.

[2] Pedersen, P.T., Valsgård, S., Olsen, D., Spangenberg, S., Ship Impacts: Bow collisions, International Journal of Impact Engineering, Vol. 13, No. 2, 1993, pp. 163-187.

[3] CowiConsult Inc, Sunshine Skyway Bridge - Ship Collision Risk Assessment, Denmark, 1998.



Kuva 16 Viisteellinen liittopalkkisilta VE2

T (Turku)

Maltholmin sillta

Parainen -Nauvo kiinteä yhteys/Nauvo, Parainen
Suunnitelman numero

Sillan kustannusarvio

Teräksinen jatkuva palkkisilta, betonikantinen, liittorakenteinen (Tjpbl)

Jännemitta (m)	55+70+95+160+95+70+55+55+70+95+160+95+70+55
Hyödyllinen leveys (m)	12,5
Vapaa-aukko (m)	150
Vinous (gon)	
Kokonaispituus (m)	1212
Kannen pituus (m)	1201,5
Suunnittelukuorma	Lk-I, Ek-I, Tiel-99

Rakenneosien numerointi

000 Koko silta
400 Päällysrakenne
600 Varusteet ja laitteet

Suunnittelutoimisto

SUUNNITTELIJA	TILAAJA
Laati: 4.9.2008	Tarkastus
Eero Meuronen	
Tarkasti: 9.12.08	Hyväksyntä
Torsten Lunabba	

Littera	*Kustanuksen laatu*	*Määrä*	*Yks*	*Yks hinta*	*Kustannus*	*Summa*
7100	SILLAN RAKENTAMINEN					
7110	SILTOJEN PERUSKUOPPIEN KAIVUT JA LOUHINNAT					
7111	Kaivu ilman tuentaa	800	m3ktr	10	8 000,00	
7114	Louhinta + (kallion puhdistus)					
	- louhinta H = 1.0 m	95	m3ktr	41	3 895,00	11 895,00
7130	SILTOJEN PAALUTUKSET					
7133	Teräspaalut					
	- teräsputkipaalut					
	- - ø 1200...1500	5000	m	1350	6 750 000,00	
	- - kalliokärki ø 1200...1500	146	kpl	3500	511 000,00	
	-- kaluston siirto	1	kpl	15000	15 000,00	7 276 000,00
7140	PERUSTUKSET					
7141	Teline- ja muottityöt	1500	m2	70	105 000,00	
7142	Raudoitustyöt					
	- betoniteräs A500HW	200000	kg	2	400 000,00	
7144	Betonointityöt					
	- Massan hankinta					
	- - betoni K30	2800	m3	100	280 000,00	
	- Betonointi	200	m3	75	15 000,00	
	- Vedenalainen betonointityö	2600	m3	400	1 040 000,00	1 840 000,00
7150	MAATUET (PÄÄTYTUET)					
7151	Teline- ja muottityöt	550	m2	90	49 500,00	
7152	Raudoitustyöt					
	- betoniteräs A500HW	25000	kg	2	50 000,00	
7154	Betonointityöt					

Littera	*Kustanuksen laatu*	*Määrä*	*Yks*	*Yks hinta*	*Kustannus*	*Summa*
	- Massan hankinta					
	- - betoni K35	190	m3	100	19 000,00	
	- Lisäaineet					
	- - pakkasenkestävyys P30	190	m3	30	5 700,00	
	- Betonointi	190	m3	70	13 300,00	137 500,00
7160	VÄLITUET					
	Teline- ja muottityöt	4470	m2	90	402 300,00	
7162	Raudoitustyöt					
	- betoniteräs A500HW	416000	kg	2	832 000,00	
7164	Betonointityöt		m3			
	- Massan hankinta					
	- - betoni K35	2800	m3	100	280 000,00	
	- Lisäaineet					
	- - pakkasenkestävyys P30	2800	m3	30	84 000,00	
	- Betonointi	2800	m3	100	280 000,00	1 878 300,00
7170	PÄÄLLYSRAKENTEET					
7171	Teline- ja muottityöt					
	- Muottien pystytys ja purkaminen					
	- - betonikantiset teräspalkkisillat	15000	m2	70	1 050 000,00	
	- - puristuslaatat	1400	m2	70	98 000,00	
7172	Raudoitustyöt					
	- betoniteräs A500HW	1150000	kg	2	2 300 000,00	
7174	Betonointityöt					
	- Massan hankinta					
	- - betoni K40	4800	m3	100	480 000,00	
		700	m3	100	70 000,00	
	- Lisäaineet					
	- - pakkasenkestävyys P30	5500	m3	30	165 000,00	
	- Betonointi	5500	m3	110	605 000,00	
7176	Teräsrakennetyöt					

Littera	*Kustanuksen laatu*	*Määrä*	*Yks*	*Yks hinta*	*Kustannus*	*Summa*
	- jatkuvat palkkisillat	4000000	kg	4,0	16 000 000,00	
7179	Pintojen verhoustyöt, impreknointi	2900	m2	10	29 000,00	20 797 000,00
7180	KANNEN PINTARAKENTEET					
7181	Eristys					
	- eristysalustan hiekkapuhallus	15000	m2	6	90 000,00	
	- kumibitumikermieristys					
	- - kaksinkertainen	15000	m2	24	360 000,00	
	- reunapalkin sisäpinnan tiivistys- sivelyt (2-kertainen)					
	- - kumibitumilla	1440	m2	11	15 840,00	
7182	Suojakerros					
	- Ab 6/50	15000	m2	8	120 000,00	
7183	Asfalttibetonipäällyste					
	- AB 12/70	15000	m2	10	150 000,00	
	- AB 20/120	15000	m2	13	195 000,00	930 840,00
7190	SILLAN VARUSTEET JA LAITTEET					
7191	Liikuntalaitteet					
	- laakerit					
	- - kumipesälaakerit	30	kpl	5000	150 000,00	
	- liikuntasaumalaitteet asennettuina					
	- - patentoidut saumalaitteet	25	m	3500	87 500,00	
	- siirtymälaatat	37	m3	450	16 650,00	
7192	Vedenjohtolaitteet					
	- tippuputket	800	kpl	30	24 000,00	
	- pintavesiputket	110	kpl	300	33 000,00	
7193	Suojalaitteet					
	- teräskaiteet (kuumasinkittyinä)					
	- - tiheä kaide	2440	m	300	732 000,00	
	- - vinot päät (4 m)	4	kpl	600	2 400,00	

Littera	*Kustanuksen laatu*	*Määrä*	*Yks*	*Yks hinta*	*Kustannus*	*Summa*
7194	Muut varusteet ja laitteet					
	- pylväiden kiinnityslaitteet					
	- - pylväät ø = 159-240	22	kpl	510	11 220,00	
	- - putket ø = < 50 (metalli)	2424	m	10	24 240,00	
7194.1	Tarkastussilta	1200	m	290	348 000,00	1 429 010,00
7200	Ennalta arvaamattomat kustannukset 10 %	1	kpl	3800000	3 800 000,00	5 229 010,00
	Rakennuskustannukset (i = 174)					**38 100 550,00**
600	**Työmaan yhteiskustannukset 25%**					**9 525 137,00**
	Sillan kustannukset (i = 174)					**47 625 680,00**
	Kustannustason noususta aiheutuva muutos					
	Pyöristys					**4 316,00**
	Sillan kustannukset (i = 174)				**€**	**47 630 000,00**
	TIETYÖT SILTAPAIKALLA					
4110	Tie-, rata-, yms. penkereet	3000	m3rtr	25	75 000,00	
5450	Kenttäkivi-, nupukivi- ja noppakivi-					
	verhoukset					
	- järjestetty kiviverhous	300	m2	50	15 000,00	
5620	Nurmiverhoukset	1000	m2	6	6 000,00	96 000,00

Littera	*Kustanuksen laatu*	*Määrä*	*Yks*	*Yks hinta*	*Kustannus*	*Summa*
	Tietöiden rakennuskustannukset (i = 174)					**96 000,00**
600	**Työmaan yhteiskustannukset 25%**					**24 000,00**
	Tietyöt siltapaikalla (i = 174)					**120 000,00**
	Kustannustason noususta aiheutuva muutos					
	Pyöristys					
	Tietyöt siltapaikalla (i = 174)				**€**	**120 000,00**
	Sillan kokonaiskustannus (i = 174)				**€**	**47 750 000,00**

YHTEENVETO JA ARVONLISÄVEROA KOSKEVA ERITTELY

Sillan kustannukset

- ilman arvonlisäveroa	47 630 000,00 €
- arvonlisävero	10 478 600,00 €

Tietyöt siltapaikalla

- ilman arvonlisäveroa	120 000,00 €
- arvonlisävero	26 400,00 €

Sillan ja siltapaikan tietöiden kustannukset

- ilman arvonlisäveroa	47 750 000,00 €
- arvonlisävero	10 505 000,00 €

Kustannukset eivät sisällä rakennuttamiskustannuksia

HANKEOSALASKENTAMENETELMÄ
laskentaversio 1/2008 (5.6.2008)

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Hanke	Parainen - Nauvo kiinteä yhteys, tierakennu	Aluekerroin = 100	Turun ympäristökunnat
Laskija	Pekka Saari		
pvm	1.9.2008		

Hinnaston kustannustaso MAKU-indeksi 4/2008 =	136,9
Kustannusarvion kustannustaso =	136,9
Hankkeen koon vaikutus	2,0 %
Toteutusympäristö	4,0 %

Hankeosat	7 422 110	82 %
Moottoriliikenneväylät	3 911 970	43 %
Kevyen liikenteen väylät	1 495 120	17 %
Muut väylät ja alueet	0	0 %
Yleiset alueet ja ympäristö	0	0 %
Liikennepaikat	0	0 %
Kaava-alueet	0	0 %
Järjestelmät	0	0 %
Energiajärjestelmät	0	0 %
Vesihuoltojärjestelmät	0	0 %
Ratojen sahköistys ja turvalaitteet	0	0 %
Ohjaus, opastus ja valaistus	0	0 %
Muut järjestelmät	0	0 %
Suunnittelu	630 880	7 %
Rakennuttaminen	556 660	6 %
Maa-alueet	0	0 %
Rahoitus ja markkinointi	0	0 %
Varaukset ja lisä- ja muutostyöt	445 330	5 %
Urakkahintaennuste	7 422 110	82 %
Yhteensä	**9 055 000**	100 %